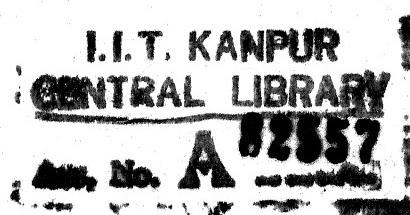


STUDY OF TECHNIQUES FOR DISPLAY OF MULTILEVEL PICTURES ON BILEVEL DISPLAYS

A Thesis Submitted
in Partial Fulfilment of the Requirements
for the Degree of
MASTER OF TECHNOLOGY

7 MAY 1982



by
Capt. S. K. MOHLA

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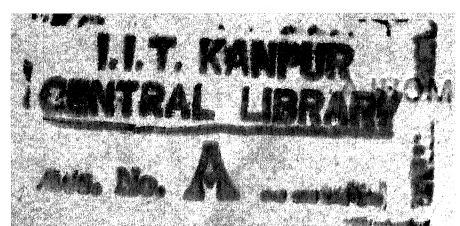
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SEPTEMBER, 1982



CERTIFICATE

Certified that the thesis entitled 'Study of Techniques
for Display of Multilevel Pictures on Bilevel Displays'
has been carried out under my supervision by Capt.S.K. Mohla
and has not been submitted elsewhere for a degree.



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LIST OF CONTENTS

	Page
Chapter I INTRODUCTION	1
1.1 Display Devices	3
1.2 Scope of the Work	8
References	13
Chapter II THE EYE AND ITS MODELS	14
2.1 The Eye	14
2.2 Modulation Transfer Function	20
2.3 The Eye Model	23
2.4 Response to Binary Patterns	30
References	38
Chapter III TECHNIQUES FOR DISPLAY OF MULTI GRAY LEVEL PICTURE ON BINARY DISPLAYS	39
3.1 Introduction	39
3.2 Orthographic Technique	39
3.3 Techniques with Equal Input and Output Resolution	42
(1) Fixed Threshold Technique	43
(2) Ordered Dither Technique	45
(3) Constrained Average Technique	49
(4) Error Diffusion Technique	53
(5) Median Technique	57
References	59
Chapter IV CONCLUSION	60
4.1 Evaluation of Techniques	61
References	63
Appendix A PICTURES GENERATED BY THE VARIOUS ALGORITHMS	
Appendix B COMPUTER PROGRAMS WITH LISTING	
Appendix C COMPUTER RESULTS	

ABSTRACT

This work is a study of processing techniques for presenting continuous tone or computer generated multi gray level pictures on bilevel displays. These displays are bilevel in nature and have individual display cells, all of the same size, arranged in a rectangular array. Six processing techniques have been discussed. All the techniques achieve the subjective effect of continuous tone by properly controlling only the spatial density of bilevel display states.

A nonlinear model of the human visual system has also been considered to show analytically the eye's perception of spatially arranged binary patterns as different gray levels. Two sets of such binary patterns have then been used to display a computer generated picture.

In the remaining processing techniques the input image is divided into picture elements (pixels) and intensity of each pixel is then compared with a threshold value. The corresponding output pixel is turned to bright state if the intensity is greater than the threshold. The processing techniques differ in the manner the threshold value is calculated. Images processed by all the techniques are exhibited, evaluated and compared.

CHAPTER I

INTRODUCTION

This work is a study of techniques/algorithms that can be used to transform a multi-level continuous tone/computer generated still, monochrome image for reproduction on binary displays/printing systems. In other words, the algorithms transform a multi-gray level picture into a bilevel picture which retains the same gray tone effects because of the transformation of the multi-level picture into spatially encoded representations compatible with binary displays. A continuous tone image is one which contains an apparent continuum of gray levels. Some scenes when viewed by the human eye may require upto or more than 256 discrete gray levels to give the appearance of a continuum of gray levels from one shade to another. Examples of continuous tone images are television (CRT) images, photographic images and real world scenes viewed by a camera.

The bilevel/binary output images produced by the algorithms discussed in the subsequent chapters differ from other bilevel images like halftone images, and line copy images. In the bilevel pictures produced by these algorithms, the dots (or the dark spots) in the output have the same size and the gray level effect is obtained by their spatial

arrangement. Algorithms discussed for achieving this spatial arrangement are of two types; one where the resolution of both the input as well as the output image is the same, and second, when the resolution of the output image is higher than the input image.

Halftone imagery is also a bilevel image which gives the subjective effect of a continuum of gray levels. The halftone techniques were developed in the mid 19th century for approximating the gray levels available in the natural imagery. There are three main techniques - lithography, letter press and gavure; and all these produce the gray levels via the presence or absence of opaque ink on a page. In order to represent the continuum of gray levels, high frequency line and dot structures are printed which have their width varied spatially throughout the scene to yield a varying percent reflectance across the page. The end result is that when such images are viewed at normal viewing distances, the dot or line structure is not noticeable but the varying average gray level produces an approximation to a natural scene. Examples of halftone images are the pictures printed in books and newspapers.

The third class of bilevel pictures is the line copy imagery. This imagery is composed of alphanumeric characters, straight line segments and solid areas of a

single gray level. This class of images are essentially made up of only two gray levels but unlike the halftone images, the dots and lines of visible size are used. Examples of this imagery are books, magazines (less their halftone pictures) and maps.

1.1 DISPLAY DEVICES

Many displays are basically bilevel in nature which have individual display cells of the same size arranged in a rectangular array. Individual display cells or sites are either on or off; bright or dark; white or black; reflective or absorptive. Examples of these kinds of displays are : Direct view storage tube (DVST), liquid crystal displays, AC-sustained gas discharge or plasma panels. The algorithms studied are used for display of images on such displays.

These display devices have inherent image storage capability and overcome the disadvantage of refresh displays of CRT. DVST resembles a CRT in that it uses a similar electron gun and a phosphorus coated screen. The difference is that the phosphorus has extremely long persistence and the beam does not write directly on the phosphorus, but on a fine mesh wire-grid coated with dielectric and mounted just behind the screen. A pattern of positive charge is deposited on the grid, and this pattern is transferred to the phosphorus by a continuous flood of electrons issuing

from a separate flood gun. Just behind the storage mesh is a second grid, the collector, whose main aim is to smooth out the flow of flood electrons. These electrons pass through the collector at a low velocity, and are attracted to the positively charged portions of the storage mesh but repelled by the rest. Electrons not repelled by the storage mesh pass right through it and strike the phosphorus. To increase the energy of these slow moving electrons to create a bright picture, the screen is maintained at a high positive potential. Fig. 1.1 shows the general arrangement of the DVST. The outputs of the study have been generated on such a device, the Tektronix 4006-1, which incorporates a 7 by 10 inch DVST and a built in alphanumeric keyboard.

The AC-plasma panel functionally is very similar to the DVST, even though its construction is very different. Images can be written onto the display surface point by point; each point remains bright after it has been intensified. Construction of the plasma panel is shown in Fig. 1.2. It consists of two sheets of glass with thin, closely spaced gold electrodes attached to the inner faces and covered with a dielectric material. The intervening space between the sheets of glass is filled with neon-based gas and sealed. By applying voltages between the electrodes the gas within the panel is made to behave as if it were divided into tiny cells, each one independent of its neighbours. A

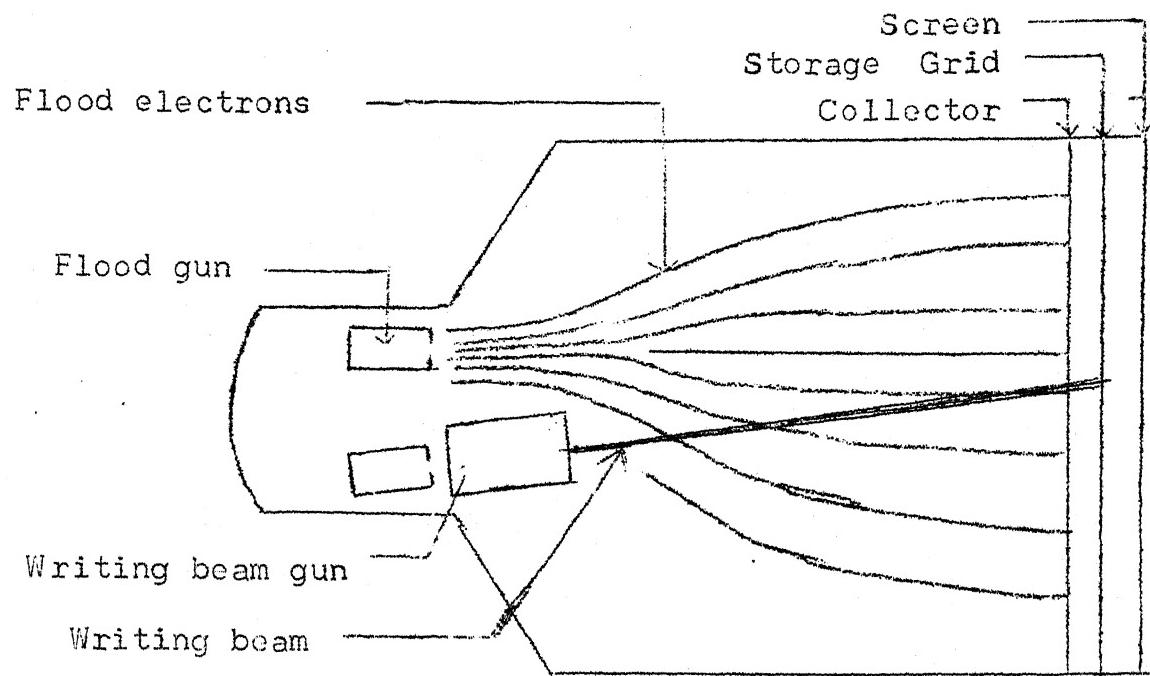


Fig. 1.1 The Direct-View Storage Tube

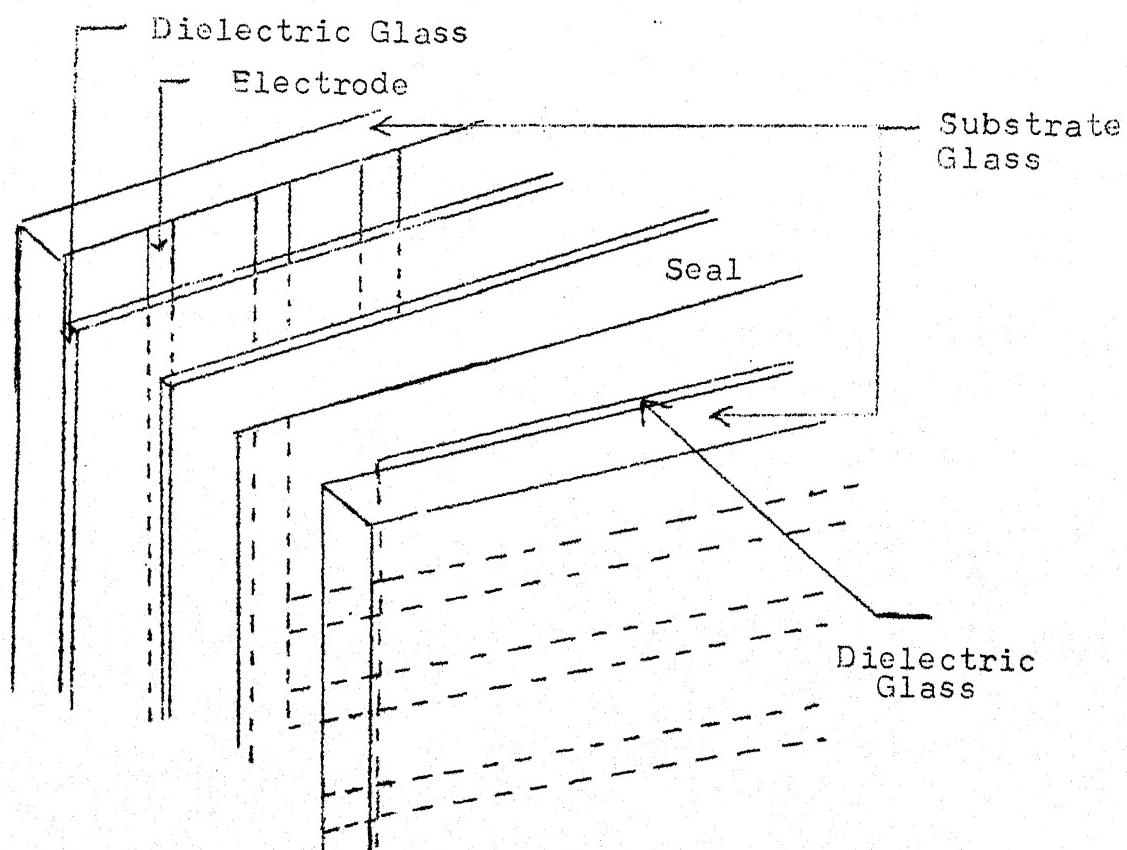


Fig. 1.2 The Plasma panel

cell is made to glow by placing a firing voltage across it by means of electrodes. The gas within the cell begins to discharge, and this develops rapidly into a glow. The glow is sustained by maintaining a high frequency AC voltage across the cell.

Among the newer display techniques, the thermal effects in liquid crystals are made use of to display pictures. Fig. 1.3 shows an arrangement using liquid crystals. It employs a laser beam for writing. Here, all the liquid-crystal molecules are assumed to be initially aligned perpendicular to the glass plates, making the layer appear clear. When scanned with the modulated laser beam the energy absorbed results in local heating. This raises the material above the transition temperature, causing the molecules to become completely disordered. After the removal of the laser beam, the material cools rapidly and the molecules remain randomly oriented, producing a scattering effect which stays for very long. The antireflection layer is provided to increase the absorption of energy from the laser beam. Light which enters clear elements of the liquid crystal is reflected back from the rear aluminium electrode. This light reaches the screen through the aperture. However, the light reflected from the scattered elements is emitted in a variety of directions with a large fraction being unable to pass through the aperture. Since

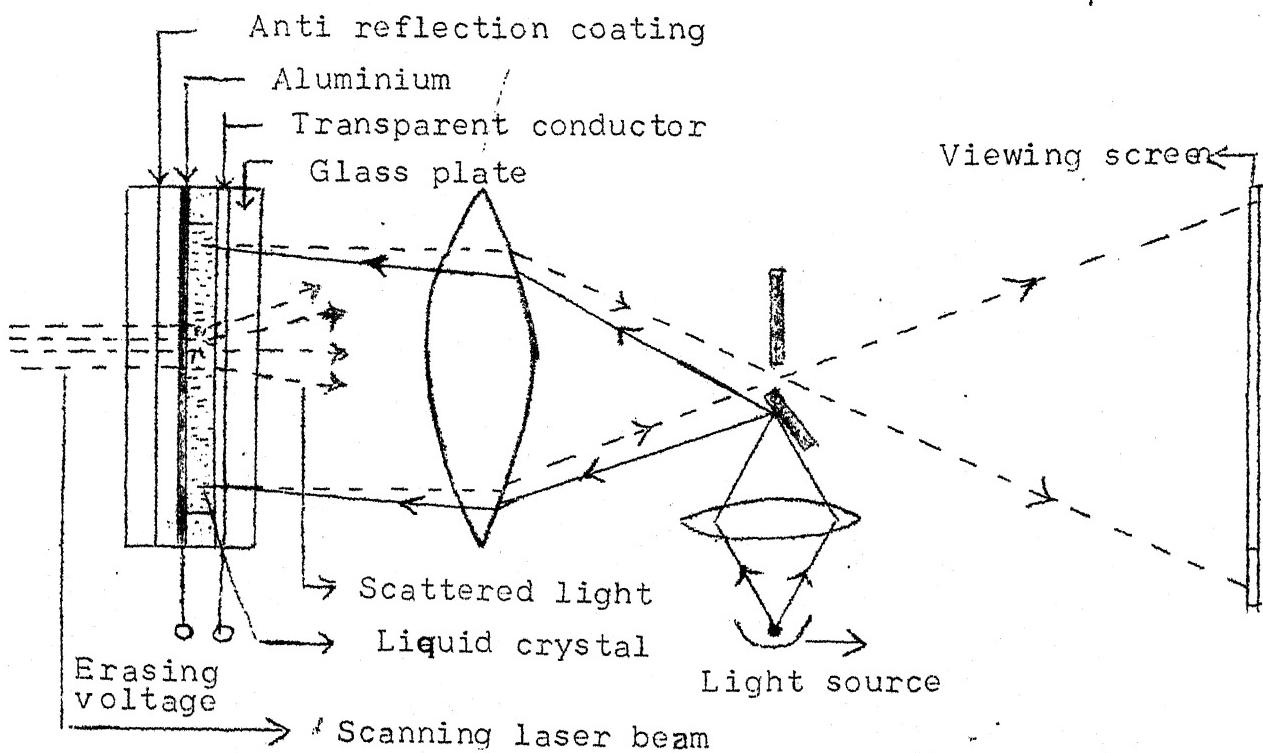


Fig. 1.3 The liquid crystal display

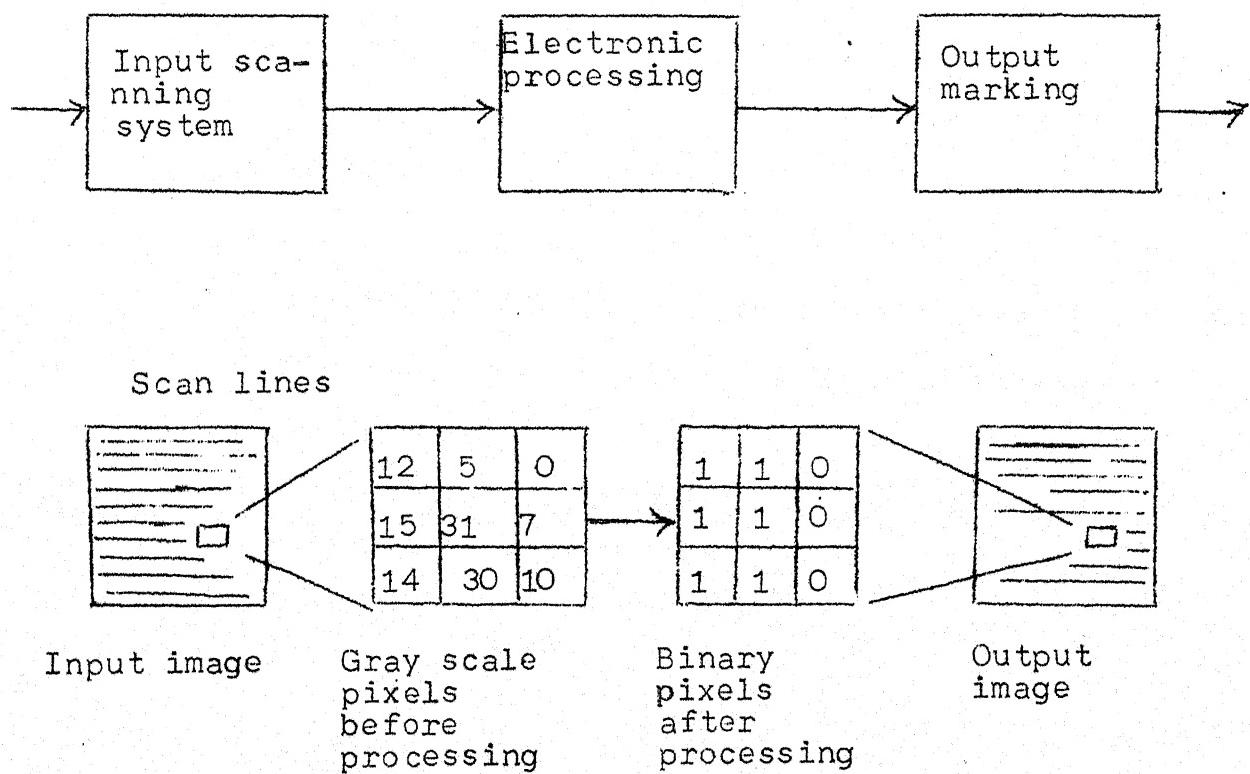


Fig. 1.4 Functional block diagram of bilevel image processing

the lens also serves to image the liquid crystal layer into the viewing screen, elements addressed by the laser beam appear as a pattern of dark spots against a light background on the screen. The above devices are discussed in detail in [1] and [2].

1.2 SCOPE OF THE STUDY

We can model the picture processing problem as given in Fig. 1.4. The input is restricted only to multilevel computer generated and continuous tone pictures and the output is a binary picture. The algorithms are used to process the pictorial input for high fidelity binary output pictures. The processing involves the selection of a threshold value which is used to spatially arrange the dots/blanks at the output.

The study has been carried out with the help of a 32-gray level computer generated picture of Abraham Lincoln. This picture has been chosen from a set of 32-gray level pictures given as 64x64 matrix of sampled intensity values at Appendix 'A' of [3]. The algorithms are applicable to any continuous tone picture whose scanned intensities are available. The processing has been done by simulation on the DEC-10 system and the hard copies of Lincoln's pictures have been obtained with the help of the plotter available with the Tektronix 4001-6 graphics terminal. The pictures generated are of three sizes; 64x64, 128x128 and 256x256.

The available 64x64, 32-level data of Lincoln's picture was processed to generate the 128x128 and 256x256 sized data. The data was processed in two ways : repetitive and random. In the former, each pixel's gray value was replaced by a 2x2 or 4x4 matrix consisting of the same pixel gray value repeated to generate 128x128 and 256x256 sized data respectively. For random processing the data was generated by generating a set of random numbers lying in the interval between the pixel's gray value and the gray average over a 3x3 window. The required number of these random numbers were then chosen and used to replace the original value. The computer programs used for generating these data, DIST.FOR and FDIST.FOR are attached at Appendix B. To generate the random numbers the NAG library subroutine G05DDF was used.

To evaluate and compare the various algorithms, the correct method perhaps would be to assess the pictorial outputs by subjective tests involving a number of subjects evaluating and responding to the quality of the picture. Since that is a long process and will probably be more suitable for a specific application, three image quality metrics given below were chosen as reasonable components or embodiments of the subjective judgements.

(a) Low Frequency Rendition : Capability of the process to reproduce the low frequency pictorial information in the input.

- (b) High frequency Rendition : Capability of the process to reproduce fine details. That is to say that an algorithm capable of reproducing the same contrast as that of the input will be superior to an algorithm which reproduces the same fine detail with lesser or no contrast.
- (c) Processing Artifacts : This implies those details in the output picture which are not part of the original picture but have appeared as a result of the processing technique. False contours are a type of artifact and may be caused due to the gray level quantization step which are sufficiently large to create a visible contour when the input image is truly a smooth, gradual variation from one to the other gray level. Another type of artifact which is similar to the false contour is caused by the output patterns. In order to get a gray level with the help of the binary process, called orthographic technique, use of binary patterns over some area is made to provide an average reflectance which is equivalent to a desired gray level. Such output patterns may create certain textures.

Another metric which may be used to compare and evaluate the various algorithms is the complexity of each of these algorithms in implementation. Though the algorithms are not very complex but keeping in view the real time implementation, even small computational difference may also

turn out to be of reasonable importance. The measure utilized is the 'context' required by each algorithm. The context is defined as the size of the memory required to determine the output state of a given pixel. For example, in a single level thresholding (like the fixed thresholding) the decision over the state corresponding to a given pixel is simply made by just that pixel being made available whereas, in case of an algorithm where a window (local) average has to be computed before the state of the output pixel can be decided, the context is the number of pixels required in the computation of the average. As seen, it does not consider operations like number of multiplications etc. to gauge the complexity.

No study of image processing is complete without reference to the capability of the human visual system as all the pictures are ultimately viewed by humans only. Towards this end the perception by the eye is of specific importance as the eye sees the gray level in the binary picture due to its inherent property of spatial integration. Efforts have been made to approximate the eye by a mathematical model. One such model has been chosen from the various models available in the literature and the processing has been done for a set of 3x3 binary patterns as inputs. The output 2-dimensional arrays give the mathematical approximations to what the eye sees. Some of these outputs have been plotted with the help of 2-dimensional hidden line plots to give the

effect of a surface seen by the eye. This aspect has been covered in Chapter II. Subsequently sets of 4x4 and 6x6 binary patterns have been chosen to output the Lincoln's picture by the orthographic technique. The resulting picture is a 256x256 and 384x384 pixel picture respectively as for each pixel of the input picture we print a 4x4 or 6x6 binary pattern at the output.

Other techniques discussed differ from the orthographic technique in that they have the same resolution at the input and output. Eye's perception of gray levels in such pictures is spread over a small area to give a general effect of an average gray level.

To facilitate comparison between the various algorithms, the following notations have been used. A frame is defined as a set of N^2 samples taken on a square geometric grid of N lines with N samples per line. In this study, three different values of N (64, 128 and 256) have been considered. Each of the N^2 samples is the intensity value $I(x,y)$ of the point (x,y) in the picture, subscripts x and y fixing the position within a line and within a frame. Since the Lincoln's picture is a 32 level picture, $I(x,y) = 0$ implies the darkest gray level and $I(x,y) = 31$ means the brightest gray level. $O(x,y)$ denotes the displayed intensity which is either 0 or 31 as the picture displayed either has a dot or a blank.

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- [2] Mclean Schagen, 'Electronic Imaging', Academic Press, 1979.
- [3] Rafel C. Gonzalez and Paul Wintz, 'Digital Image Processing', Addison-Wesley Publishing Co., 1977.

CHAPTER II

THE EYE AND ITS MODELS

Light as per Webster's dictionary is : 'radian energy which by its action on the organs of vision, enables them to perform their function of vision'. Light as we know is a form of electromagnetic radiation lying in the relatively narrow region of the electromagnetic spectrum over a wavelength band of about 350 to 780 nm. The mechanisms by which the light interacts with the 'organs of vision' is not very well understood. However, an attempt is made in this chapter to review some of the mathematical models of the eye available in the literature and then one of them is chosen and used to show analytically how the eye perceives a fine binary pattern structure(of dots and blanks) as different gray levels.

2.1 THE EYE

A conceptual technique for the establishment of a model of the human visual system (HVS) would be to perform a physiological analysis of the eye, the wave paths to the brain, and those parts of the brain involved in visual perception. Such a task, of course, is beyond the ability of the man because of the large number of infinitesimally small elements in the visual chain and their complex interconnections. Fig. 2.1 contains a sketch of the horizontal

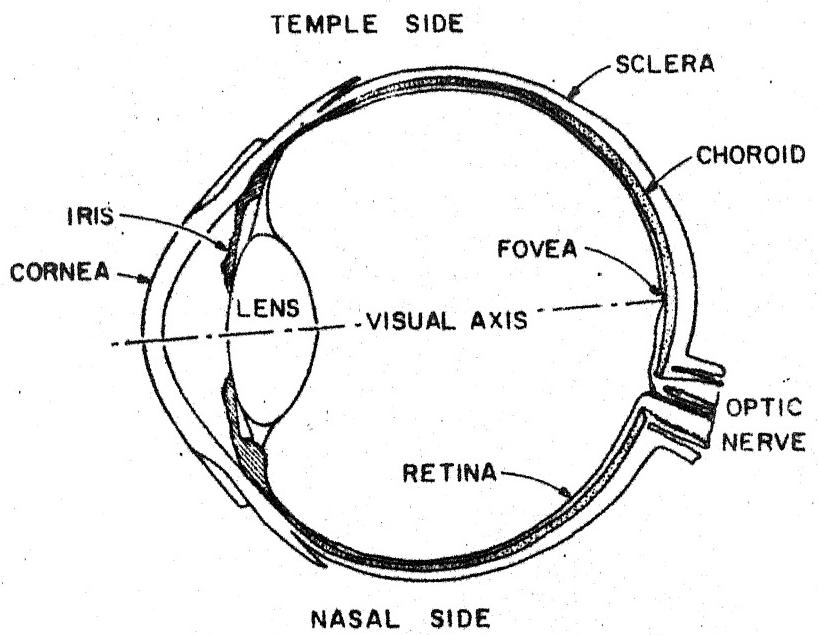


FIGURE 2-1 Eye cross section.

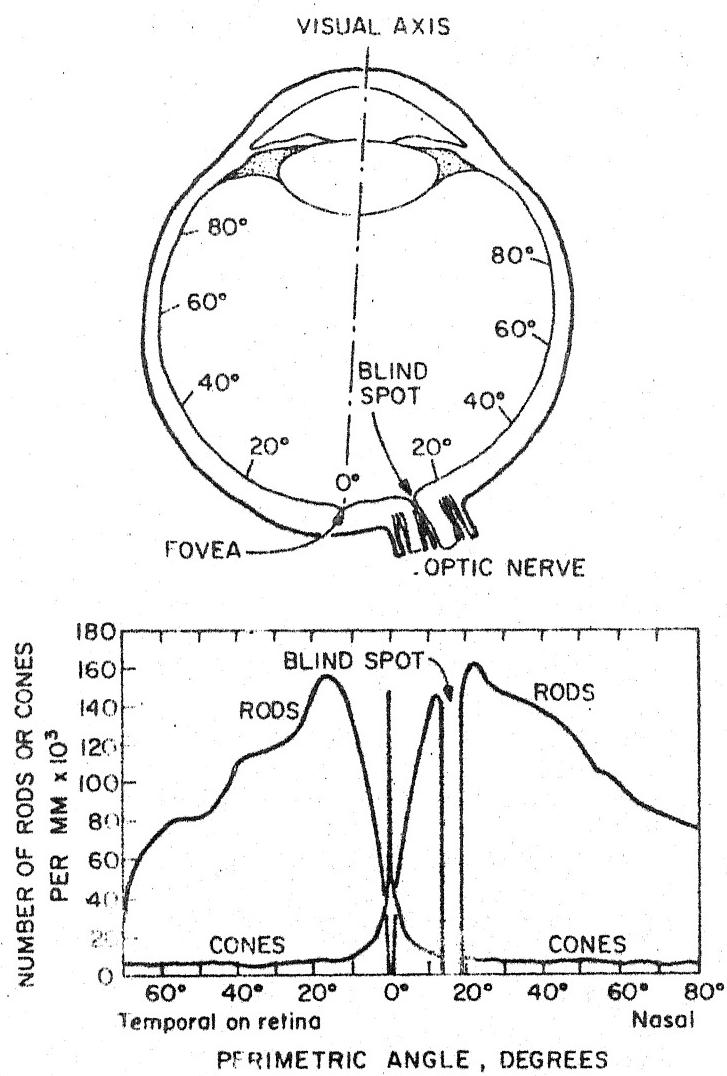


FIGURE 2.2 Distribution of rods and cones on retina

cross-section of the human eyeball. The front of the eye is covered by a transparent surface called the cornea. The remaining outer cover called the sclera, is composed of a fibrous coat that surrounds the choroid, a layer containing blood capillaries. Inside the choroid is the retina, which is composed of two type of receptors - rods and cones. Nerves connecting to the retina leave the eyeball through the optic nerve bundle. Light entering the cornea is focussed to the retinal surface by a lens that changes shape under muscular control to perform proper focussing of near and distant objects. An iris acts as a diaphragm to control the amount of light entering the eye. The rods in the retina are long slender receptors, while the cones are generally shorter and thicker in structure. Operationally, the rods are more sensitive than cones to light. At low levels of illumination, the rods provide a visual response called scotopic vision. Cones respond to higher levels of illumination; their response is called photopic vision. An eye contains about 6.5 million cones and 100 million rods distributed over the retina. Fig. 2.2 shows the distribution of rods and cones over a horizontal line on the retina. At a point near the optic nerve called the fovea, the density of cones is greatest. This is the region of sharpest photopic vision. There are neither rods nor cones in the vicinity of the optic nerve, and hence the eye has a 'blind spot' in this region. When a light

stimulus activates a rod or cone, a photochemical transition occurs producing a nerve impulse. The manner in which the nerve impulses propagate through the visual system is presently not well established. It is known that the optic nerve bundle contains on the order of 800,000 nerve fibres. Since there are 100,000,000 (100 million) receptors in the retina, it is obvious that in many regions of the retina, the rods and cones must be interconnected to nerve fibres. Since, neither the photochemistry nor the propagation of nerve impulses within the eye is well understood, a deterministic characterization of the visual process is not available. However, certain models of the HVS have been presented which are taken to predict the human visual system response.

Before the HVS model is discussed, certain visual phenomena that a reasonable model must accomodate are discussed :

a) Dark adaptation of the eye :

It is well known that a person is more sensitive to dim flashes of light if he has been in dark for a period of time (as happens when one enters a movie hall). Cornsweet [1] has shown that the cones are adapted to dark in about 5 minutes whereas the rods take much longer (about 30 minutes).

b) Threshold intensity for perception :

It is the lowest possible intensity that the eye can see. It is dependant upon the colour, location with respect to the eye, timing and size of the light. The state of the subjects eye will also affect the threshold value. Any light lost before it reaches the rods (being the primary receptors at low intensities), cannot affect the subject as he does not assimilate any information about the light if it is not absorbed by the visual pigment in the rods. It has been shown by Cornsweet (p.25) that after catering for all the losses of light like reflection from the eye, absorption by the pigment that fill the eyeball itself, and the loss due to the inter rod spacings; about 10 quanta are absorbed, but they are spaced over an area which has 500 rods. Probability of one rod absorbing two quanta of light will be very small and hence one quantum is sufficient to stimulate a single rod and approximately 10 rods within a 10 μm diameter area must be stimulated within 1 msec of each other before the stimulus is perceived. Hence, the activation of 10 rods is somehow added up in the visual system. This threshold is for monocular vision. The binocular threshold is lower by a factor of $\sqrt{2}$ as mentioned by Hall [2].

c) Simultaneous contrast

It is commonly experienced that the brightness of a region does not depend upon its intensity only but also upon

the surround. If we look at a thick (opaque) gray or coloured paper with one eye under any ordinary light and then hold it up at an arm's length between the eye and a bright sky or a large light source, the paper will look much darker when it is in front of the light source, even though the actual amount of light reflected from the paper is the same. In fact, if the background light is bright enough the paper will look black when held in front of it.

d) Brightness constancy :

It implies that the brightness of any object remains fairly constant despite large changes in the illumination that falls on it. For example, a piece of ordinary white paper reflects about 99 percent of the incident light, while black papers reflects about 10 percent. When these papers are moved from ordinary room light illumination into direct sunlight, the incident illumination and therefore, the reflected light intensity may increase by 1000 fold; yet the papers still have about the same brightness as they had indoors. Furthermore, the black paper outside reflects $0.10 \times 1000 = 100$ relative units of intensity and the white paper inside reflects only $0.9 \times 1 = 0.9$ units; but the black paper outside still looks darker than the white paper inside.

e) Mach bands :

Consider a set of gray scale strips, each having the same gray level, the darkest strip towards the left extreme and the brightest towards the right extreme. The reflected light from each strip is uniform over its width and differs from its neighbours by a constant amount. Nevertheless, the visual appearance is that each strip is darker at its right side than at its left side. This is called the Mach Band Effect. The effect is due to the spatial frequency response of the eye, which possesses a lower sensitivity to high and low frequencies than mid-frequencies.

2.2 MODULATION TRANSFER FUNCTION (MTF)

In order to postulate a model for HVS, it is necessary to have a method which can be used to predict the response of the HVS given a particular input. Since our concern in this study is the spatial response of the eye, the processing model is based upon the amenable frequency measurements.

Since any spatial pattern can be broken down into various sine wave components by Fourier Analysis, the procedure to measure the MTF is to feed a sine wave grating as the input. Cornsweet [1] has explained this method with the help of an optical lens to which sine wave gratings of different frequencies are input and the outputs are studied to calculate the MTF of the lens. It is seen that as the

frequency of the gratings is increased, the amplitude of the modulation of the image distribution (i.e., the difference between the intensity at each bright part and at each dark part) becomes smaller and smaller and for extremely fine gratings, the modulation in the image becomes zero and a uniform intensity distribution is seen. The property of the lens being measured is its ability to transfer spatial modulation of intensity from the object to the image. Hence, the MTF of the lens is an indication of its ability to resolve gratings. In the experiment above, the phase shifts have been assumed to be zero. If say, the phase shift introduced by the lens was constant for all the frequencies, then the image would merely be shifted from the expected position. However, if the phase shifts vary with frequency then the MTF alone would not be sufficient to define the image of any object as the relative positions of the various sine wave components would not be known. Therefore, if there were substantial phase shifts varying with frequency, both the MTF and the phase shift at each frequency would have to be known in order to predict the image correctly. However, the phase shifts produced by most lenses and by the optical system of the human eye are relatively small near the optic axis (fovea for the eye) and only trivial errors are introduced by assuming zero phase shifts.

Before we use the concept of MTF for the eye model, it is necessary and essential to list out the conditions that must be met in order to use Fourier techniques.

a) Linearity :

A linear system is one that obeys the principle of superposition, i.e., if two inputs give the outputs X and Y, then when both the inputs are applied simultaneously, the system output should be X+Y. In general, if the intensity radiated from the object is increased, the magnitude of the response of the system should increase proportionately. We may also apply the technique over the linear operating region of a nonlinear system.

b) Homogeneity :

A system is spatially homogeneous if its characteristics are the same in all locations. If a system is homogeneous, then shifts in the location of the input pattern may cause shifts in the location of the output pattern, but the output pattern will not change except in position. The HVS is not homogeneous due to the variation of the densities of rods and cones with retinal position. However, it is relatively homogeneous near the optic axis (i.e. near the fovea). In spite of the inhomogeneity of the HVS, Fourier techniques may be used to correctly predict its response. Cornsweet [1] has pointed out that there is probably a self homogenising process in the structurally anatomically

inhomogeneous process which renders it open for the use of Fourier techniques. Models discussed do not consider temporal responses, hence temporal homogeneity has not been considered.

c) Isotropic:

A system is isotropic if its characteristics are the same in all directions. For example, a system is isotropic if the MTF measured with sinusoidal grating objects is the same regardless of whether the gratings are vertical, horizontal or oblique, (i.e. regardless of their angular orientation with respect to the optic axis in the object plane). The response of the HVS to a rotated contrast grating is a function of frequency of the grating as well as the angle of orientation. The sensitivity of the system decreases to a minimum at 45° and then rises again reaching the original level at 90° . At the point of maximum deviation (i.e. 45°) a frequency of 30 cycles/degree would be -3 dB below the response at 0° rotation. Whereas for 10 cycles/degree the response at 45° deviation is only 15 percent lower than the original. This an-isotropic behaviour has not been included in the models discussed.

2.3 THE EYE MODEL

In the lens experiment explained in Section 2.2, the output to a particular input is visible and the transfer function can be calculated in a straight-forward manner. The

case is different for the eye, where we have no way of knowing what kind of output image is being formed in the human brain. Hence, in order to measure the modulation transfer function for the HVS, various ways have been used. But the basic principle used in all is that a subject is asked to match a variable object (grating) with a reference object (grating) and this can be done in different ways like varying the contrast or frequency.

As a direct analogy with the procedure for measuring the MTF of a lens, a human subject could be presented with a series of sine wave gratings with same amplitudes but different frequencies and then obtaining a measure of his perception of the patterns. The measure of the perception is the apparent amplitude of each sine wave, (that is, the difference between the brightness of peaks and troughs of the wave) because the apparent amplitude is exactly an 'output' of the HVS. Thus, a plot of the input frequency (for a fixed amplitude) against the apparent amplitude, would be analogous to the plot of the MTF of the lens. Given such a plot and assuming that the HVS is operating in the linear region, and that it is homogeneous and isotropic, we should be able to predict the appearance of any input pattern. Davidson [1, p. 335] has suggested one such arrangement. Assuming the HVS to be linear, homogeneous, isotropic, monocular, monochromatic and photopic (that is operating beyond threshold), a MTF was

plotted and is given in Fig. 2.3. In fact, the response is contrast dependant and the curves for different ratios of contrast have same shape with higher ratio curves, higher in amplitude. This response can be represented by a system which is just a band pass filter but it would be difficult to defend from a physiological standpoint since the response is a compound one due to several mechanisms within the HVS.

A slightly more detailed model would be a combination of a LPF and a HPF. In fact, the complete response of the HVS as in Fig. 2.3 can be depicted by a variable sine wave grating of Fig. 2.4. The figure shows sine wave gratings with frequency increasing from left to right and the contrast increasing from bottom to top. If a line is drawn horizontally across the figure, the line will intersect sinusoidal changes in intensity whose amplitude is constant but whose frequency varies. As can be seen clearly from the diagram, sensitivity of the HVS is maximum at mid frequencies and reduces at lower and higher spatial frequencies. Cornsweet (p. 343) has used this MTF to explain the Mach band effect and contrast sensitivity mentioned earlier in this chapter.

Characteristics of the high frequency response, i.e., the region that extends from peak mid frequency where the sensitivity decreases with frequency,

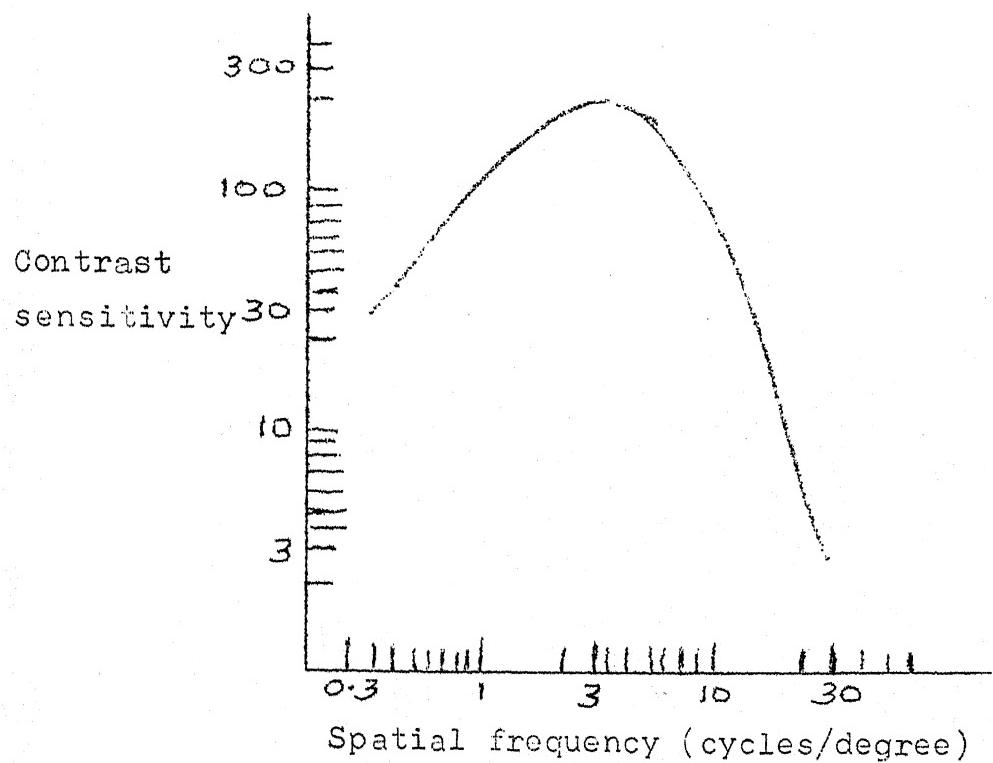


Fig. 2.3 Response of the Human Visual System

26(a)

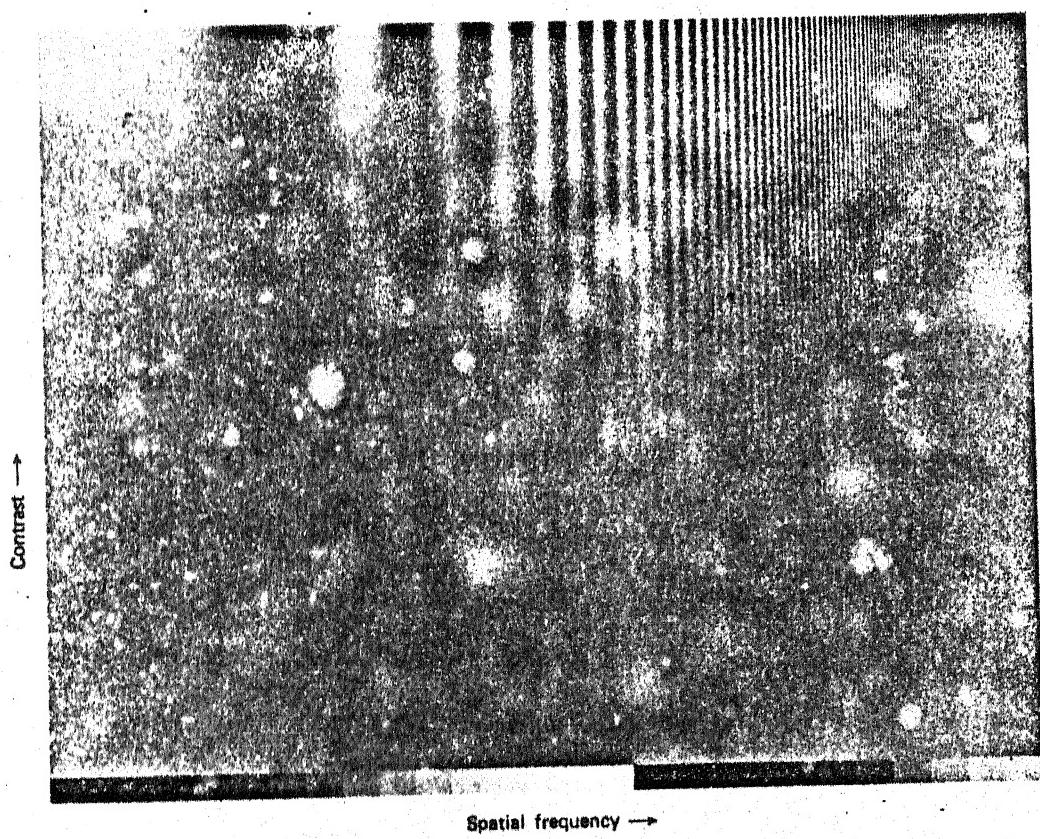


FIGURE 2.4 MTF measurement of human visual process by modulated sine wave grating.

are determined in part by the optics of the eye (lens, pupil size and cornea); also the properties of the retina itself affect the high frequency response. Size and density of the photo receptors, neural summation and scattering of light at the retinal surface affect the high frequency response of the HVS. The low frequency response is limited by the lateral inhibition.

This model of a combination of LPF and HPF can be used to approximate a HVS but it does not account for the phenomenon of 'brightness constancy'. This phenomenon can be accounted for by introducing a nonlinearity in the system. This is illustrated in Fig. 2.5(a) where the intensities in the right hand figure are all the same multiple of those on the left. If a logarithmic transformation is assumed, the figures get transformed as in Fig. 2.5(b). The two outputs now look quite similar which is how the eye perceives the black and white papers in normal illumination and under bright illumination source. That is, if a logarithmic transformation is added to the MTF described earlier, we are in a position to accomodate in the model the majority of the phenomena of the eye's perception of still, monochrome images. This nonlinearity has been studied extensively by various researchers. The studies were mainly carried out on the horseshoe crab, 'Limulus', and with the use of mechanical receptors. The choice of Limulus was motivated because

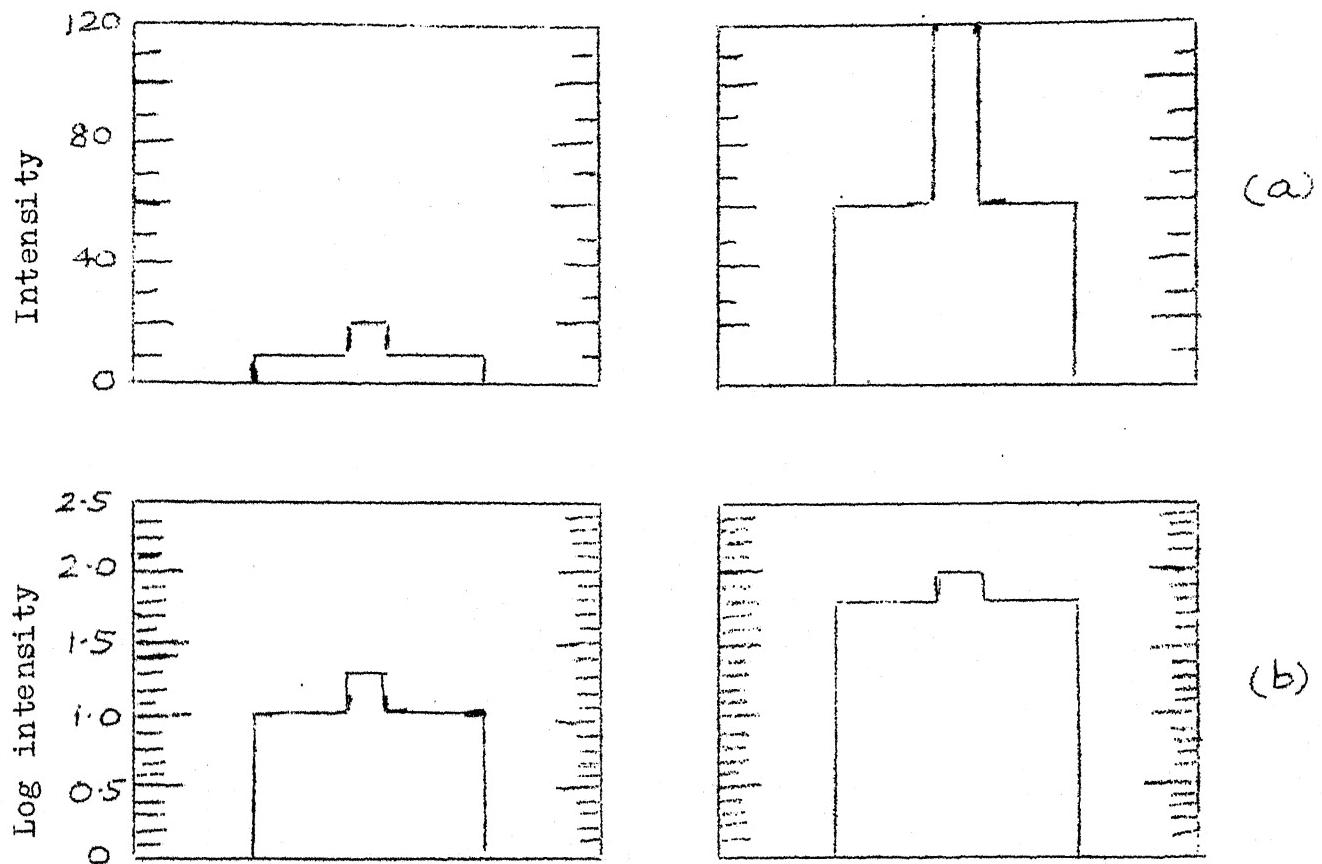


Fig. 2.5 Patterns for brightness constancy

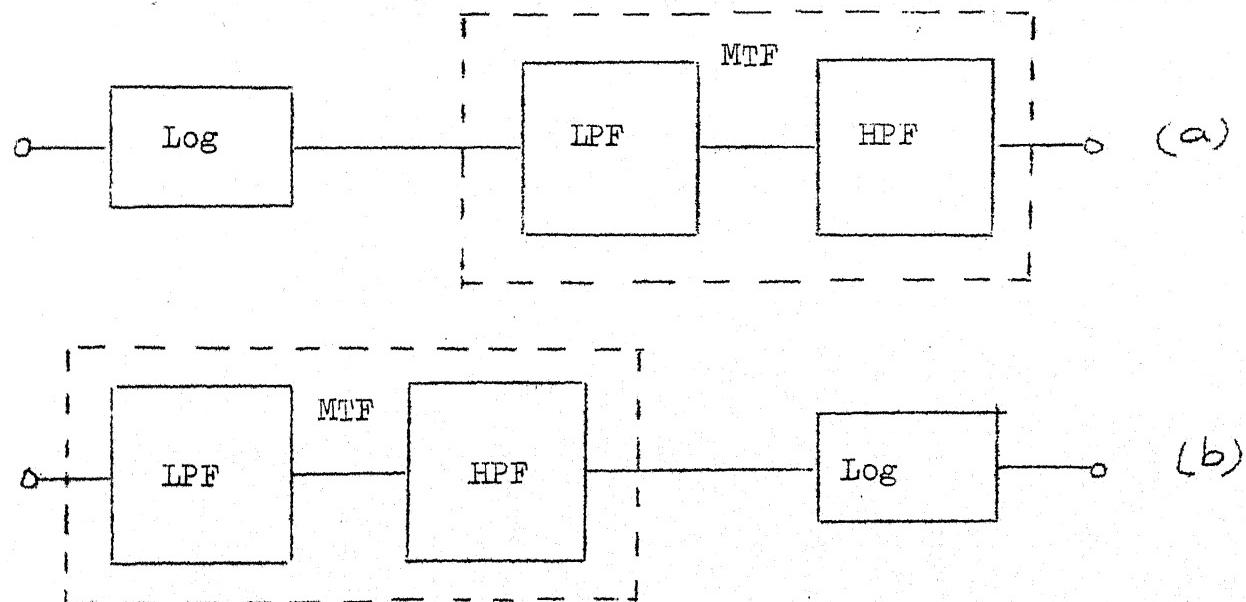


Fig. 2.6 Nonlinear models of HVS

the lateral eyes of this animal lend themselves to physiological analysis, and preliminary studies suggested that many of the properties of this eye are similar to those of higher animals, including humans. It has been shown that the nonlinearity in the HVS can indeed be approximated by a logarithmic function.

The question which arises is how a nonlinearity can be added to MTF, (a linear system). It has been argued by Cornsweet (p. 334), that for small variations in intensity of input patterns, the system essentially operates in the linear region of the nonlinearity. Also, it has been shown that under increasing light adaptation condition, the linear region becomes larger.

Two ways in which the nonlinearity can be added are shown in Fig. 2.6. Of the two structures shown Fig. 2.6(a) can be used to explain the phenomenon of brightness constancy. This system is thus physiologically sound and it also predicts the brightness constancy. This model has been chosen to process the 3x3 binary patterns. The impulse response of the LPF has been given by Campbell [3] as :

$$h_1(x) = \exp(-\alpha |x|) \quad (2.1)$$

where α has a value of 0.7 for a pupil diameter of 3 mm, Its Fourier transform is given by

$$H_1(\omega) = \frac{2\alpha}{\alpha^2 + \omega^2} \quad (2.2)$$

The -3 dB point occurs at approximately 6.5 cycles/degree.

The transfer function os HPF is given as :

$$H_2(\omega) = \frac{a^2 + \omega^2}{2a_0a + (1-a_0)(a^2 + \omega^2)} \quad (2.3)$$

where a_0 is the distance factor between receptors and 'a' is the inhibiting factor. This transfer function has been derived by using the backward inhibition model for the photoreceptors in HVS given in Fig. 2.7. The receptors are assumed to have a logarithmic response to the incoming light. The principle used is that there is an inhibiting effect in between the receptors in the retina. The detailed analysis has been done in the work by Hall and Hall [2].

2.4 RESPONSE TO BINARY PATTERNS

After having discussed a model for the HVS, the next step is to use it to analyse its response to a set of patterns of binary pixels. As was mentioned briefly in Chapter I, due to the spatial integration properties of the eye, a set of properly chosen closely spaced binary patterns with their basic repetition frequency beyond the eye's cutoff range are perceived as different levels of brightness. This property is usefully utilized to transform multilevel computer generated (or continuous tone) pictures into binary pictures which retain the gray level effects due to the spatial arrangement of the binary patterns.

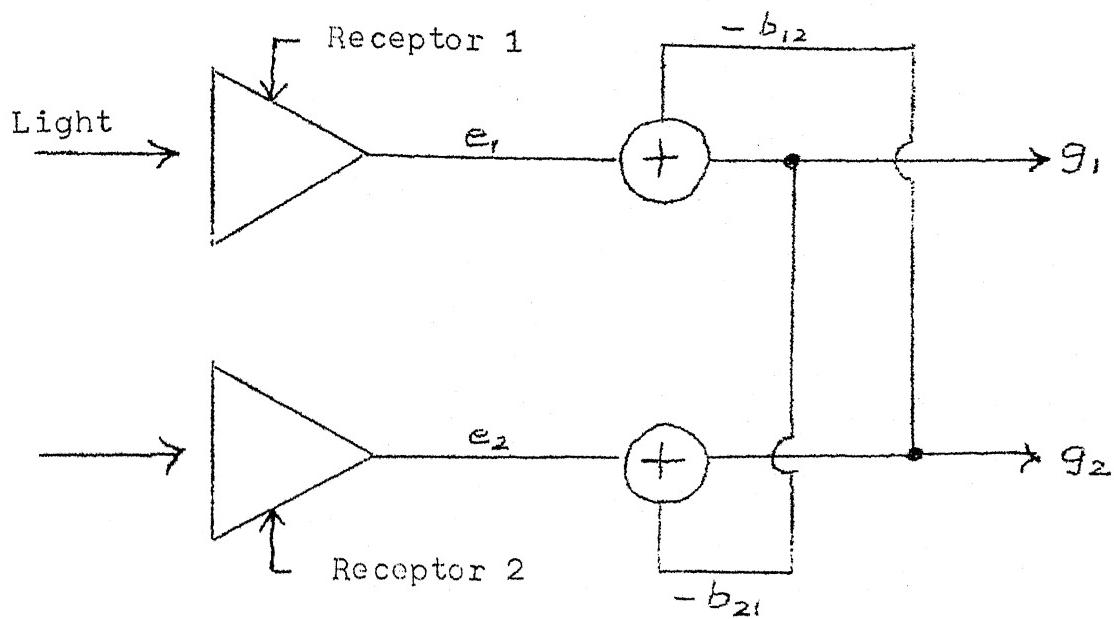


Fig. 2.7 Backward inhibition model

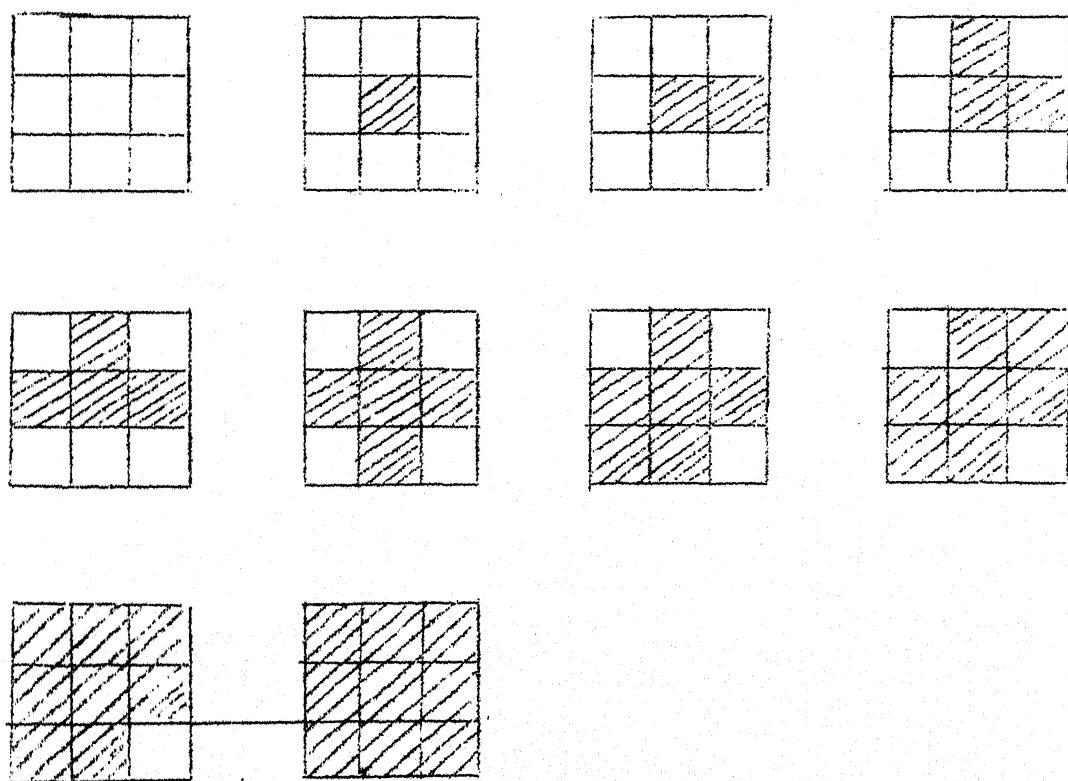


Fig. 2.8 Set of 3x3 patterns

A set of 3x3 such binary patterns which can be used to display 10 intensities are given in Fig. 2.8. This set of binary patterns has been taken from the book by Newman and Sproull [4]. These patterns are input to the model of the HVS and the outputs obtained with the help of the computer program PROC-FOR.

To find out the MTF, the impulse response of the LPF is convolved with the response of the HPF to give the overall impulse response of the model less the nonlinearity. The impulse response of the HPF is worked out as :

$$h_2(x) = \frac{C}{2D} \exp(-D|x|) - \frac{1}{2DA} [D^2 \exp(-D|x|) - 2D \delta(x)] \quad (2.4)$$

where

$$A = (1-a_0) = 0.8$$

$$B = \frac{2a_0 a}{1-a_0} = 0.005$$

$$C = \frac{a^2}{A} = 0.000125$$

$$D = (B+a^2)^{\frac{1}{2}} = 0.0714$$

On substituting these values, we get

$$h_2(x) = 1.25 \delta(x) - 0.04375 \exp(-0.0714 |x|) \quad (2.5)$$

Hence, the overall response of the system is

$$h(x) = h_1(x) * h_2(x) = 1.2531 \exp(-0.7 |x|) - 0.06125 \exp(-0.0714 |x|) \quad (2.6)$$

Assuming circular symmetry, the two-dimensional response of the system is

$$h(x) = 1.2531 \exp(-0.7 |x+y|) - 0.06125 \exp(-0.0714 |x+y|) \quad (2.7)$$

The input to the eye model is one of the 3x3 binary patterns in which the dot is assigned value 2 and blank is assigned value 11. The pattern has been transformed into a two-dimensional array with the centre pixel being the origin. In order to find the response of the system, we consider only the discrete values of the system point spread function at the points at which the patterns exist. The systems response has been limited to a size of 21x21 as beyond this region the values of the output are quite small. The system response thus is the two dimensional convolution of the log of the 3x3 pattern and the MTF. The two dimensional convolution has been tried out in two ways : the usual double summation and a method suggested by MacAdam [5] to convert the 2-dimensional convolution into 1-dimensional convolution. In this method the 2-dimensional arrays are read as vectors by the computer and then 1-dimensional convolution is performed to yield a vector which is rewritten as a 2-dimensional array to give the result. Though while using the DEC-10 system the difference in the CPU time was negligible as the arrays were not large.

The computer program used to carry out this operation is named CONVOL.FOR and is attached at Appendix B. The program generates the 21x21 matrix which is the MTF of the system. The input to the program is the 3x3 binary pattern. The output is a 23x23 two dimensional array which has the centre value i.e., the 12th column of the 12th row maximum. These values progressively decrease and are minimum at the four corners of the array. As seen from Appx.C for 10 patterns (and their combinations) the centre value is highest for the brightest level, i.e., the pattern having all bright squares and is lowest for the pattern having all dots, thus the 10 gray levels are distinguished as different from each other. To get a better idea of these outputs, some of these have been plotted with the help of 3-dimensional plots with and without hidden line elimination and are shown as Figs. 2.9 and 2.10.

The 3-dimensional plotting without hidden line elimination is done by fitting a curve (using cubic spline fit) for the values generated by CONVOL.FOR. The algorithm used for this purpose has been suggested by Cline [6]. Cline has suggested curve fitting by cubic splines with tension. The tension factor removes the defect of inflection points commonly seen in the cubic spline fitted curves. With the tension factor, the curve may be assumed to be a light and flexible bar not only constrained to pass through the given values but also able to respond to a tension produced by pulling on its ends. Sufficient tension would remove the

unwanted inflection points. The program consists of the driver program SPLINE.FOR and two subroutines KURV1 and KURV2. These are attached at Appendix B. The plot drawn is shown at Fig. 2.9. This does not incorporate the hidden line elimination. The curves have been rotated by 20° to give the 3-dimensional effect.

The plotting with hidden line elimination is carried out with the help of an algorithm suggested by Watkins [7]. This algorithm incorporates hidden line elimination and the plots are rotated to give the desired 3-dimensional effect. The input to this program is the output of the SPLINE.FOR program. Program PLOT3D.FOR accepts the three dimensional data, rotates it in the three space and plots the projection of the resulting figure onto the X-Y plane. One point to note here is that the rotation carried out by PLOT3D.FOR is not in addition to the rotation carried out by SPLINE.FOR because the data output by SPLINE.FOR is in unrotated form and the rotation that was achieved was with the help of the GPGS package while drawing the plot on the screen.

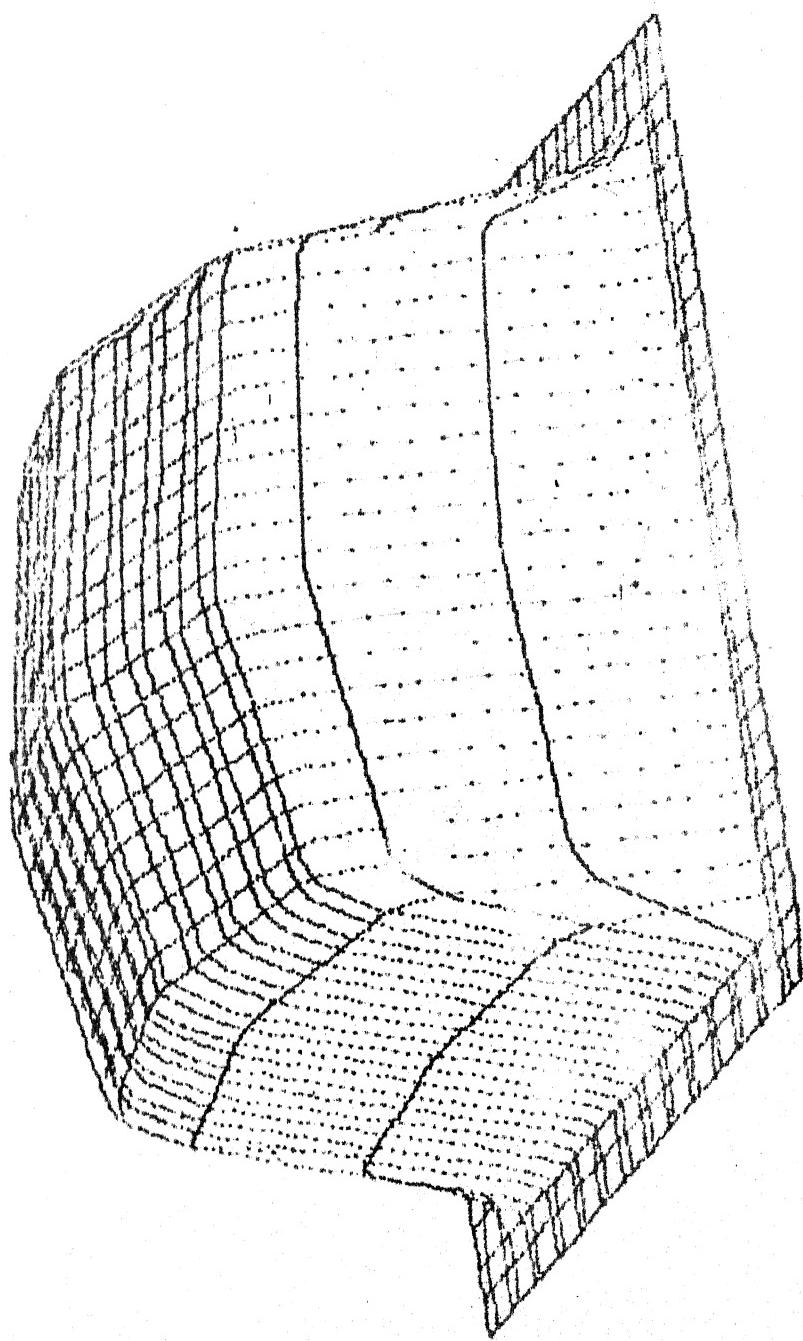


Fig 2.9

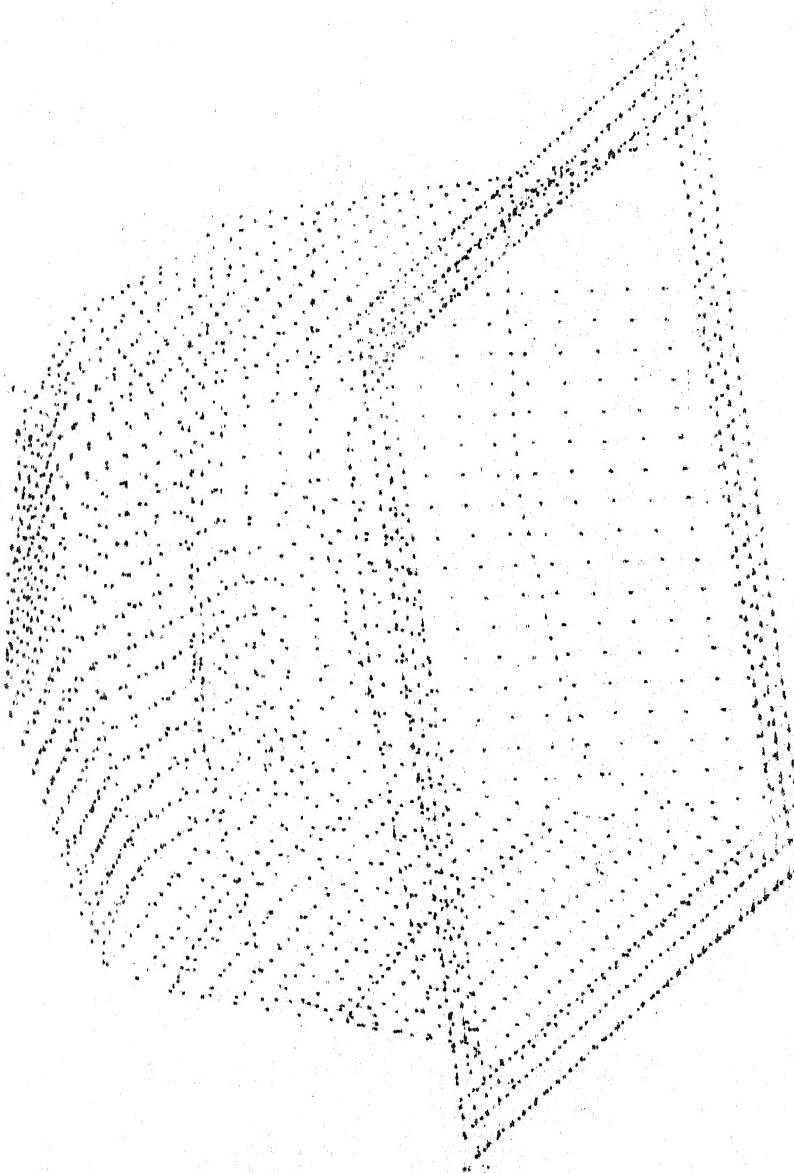


fig 2.10

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CHAPTER III

TECHNIQUES FOR DISPLAY OF MULTILEVEL GRAY
PICTURES ON BINARY DISPLAYS

3.1 INTRODUCTION

As mentioned in Chapter I, there are two classes of techniques to display multi-gray level (continuous tone or computer generated) pictures on binary displays. They differ in the relationship between the number of pixels of the input and output pictures. Gray levels were approximated by patterns of binary pixels in the previous chapter and the technique using this principle, called the Orthographic Technique, has higher number of pixels in the output picture as compared to the pixels in the input picture. The remaining techniques discussed in this chapter belong to the general class of algorithms that convey gray level information by the spatial arrangement of binary pixels which are in a one to one correspondence with the pixels in the original image. These techniques create patterns of binary pixels that preserve detail and average image brightness over extended areas.

3.2 ORTHOGRAPHIC TECHNIQUE

This technique utilizes an ' $m \times n$ ' array of binary pixels in the form of a gray scale 'character' to represent a multi-gray level picture. These characters together form a

gray scale 'font' which, when printed with minimal inter-character spacing, yield the gray scale information of the original picture.

In Chapter II a set of 3x3 binary patterns were shown and they could be used to represent a 10 gray level picture. Similarly, Hamill [1] has suggested a set of 4x4 binary pixel patterns depicting 16 gray levels. This set of patterns has been used to generate the test picture of Lincoln shown in Fig. 1 of Appendix A. The generated picture is shown at Fig.2a of Appendix A. The program used for the technique is called ORTHO-FOR and is attached at Appendix B. The algorithm simply involves a table look up process as shown in Fig. 3.1. Since the patterns number only 16, a quantization step of two has been used to represent the 32 gray levels. The program ORTHO-FOR reads the patterns as vectors of 16 and then arranges them as 4x4 patterns at the output for each input pixel. The picture generated is thus a 256x256 pixel picture.

Since the usual pictures are sampled with the help of 128, 256 or even higher gray levels, a compromise is usually developed for the size of the patterns as large sized patterns produce coarse resolution. In view of this, large quantization steps will be needed which result in tone scale errors. Because of the coarseness of tone scales, false contouring might result and the actual characters used to create gray

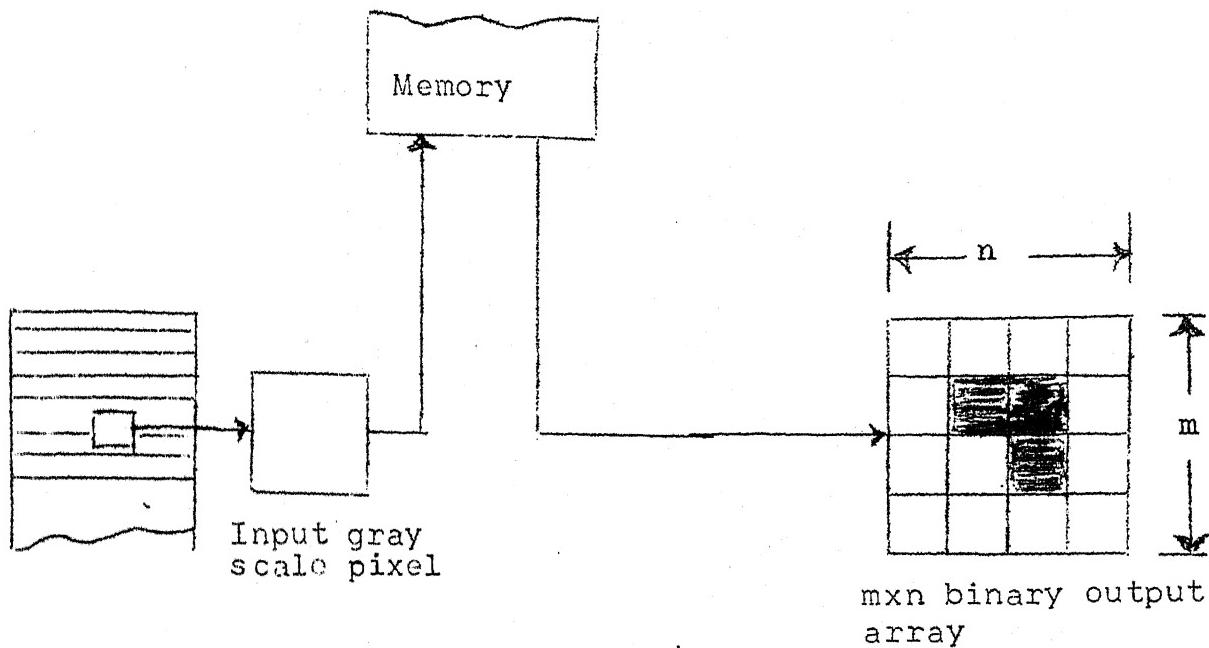


Fig. 3.1 Signal flow diagram for Orthographic Technique

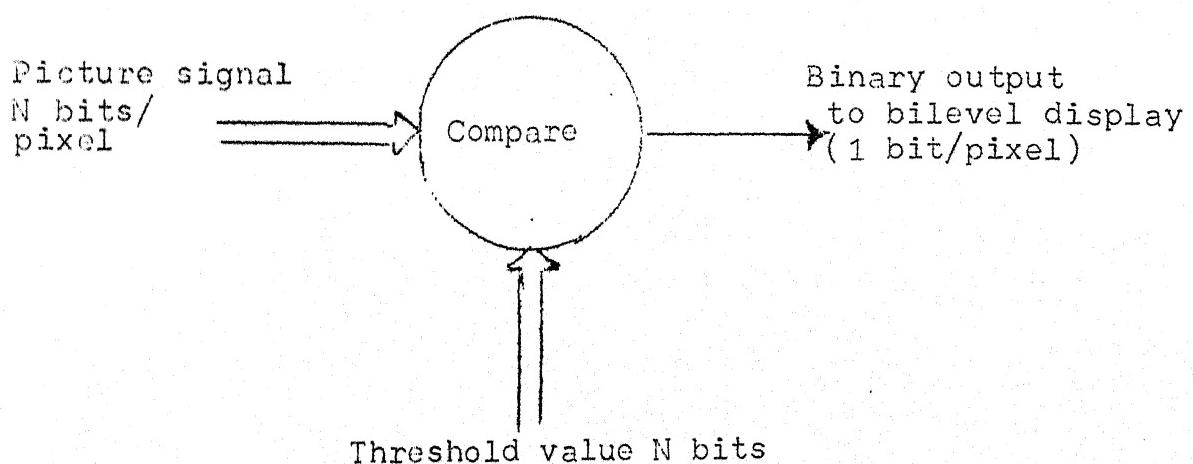


Fig. 3.2 The basic processing organisation

scales may also become visible. The 4x4 patterns used for the generation of the picture in Fig. 2a of Appendix A are visible. In certain cases, depending upon the selection of fonts, texture contours might be visible in the output picture. There is no processing complexity as the technique simply requires a pixel look up table.

The set of patterns suggested by Hamill were modified into 6x6 binary patterns to represent 32 gray levels. The picture generated by this set is as shown in Fig. 2b of Appendix A. Using the same set of 6x6 patterns another picture was generated and is shown at Fig. 9 of Appendix A. The quality of this picture is poorer than the picture of Fig. 2b of Appendix A. This was caused due to a programming error. A similar error in the program using Hamill's 4x4 patterns resulted in the absolutely distorted picture of Fig. 8 of Appendix A. In this, the data has been compressed and repeated to give the distortion where smaller sized pictures of Lincoln have been superimposed on the original picture.

3.3 TECHNIQUES WITH EQUAL INPUT AND OUTPUT RESOLUTION

The basic processing organisation that produces the binary output for the generation of the output picture is shown in Fig. 3.2. Intensity of each pixel of the input picture is compared with a threshold signal. If the intensity of the pixel is greater than the threshold the

corresponding output pixel is set to bright state, otherwise the output pixel is set to dark state. The various techniques described in this section differ primarily in the way they produce the threshold values for comparison with the intensity of the input pixel.

3.3.1 Fixed Threshold Technique

Fig. 3.3 shows a schematic diagram for a globally fixed level thresholding process with input $I(x,y)$ and output $O(x,y)$. This technique is simplest to implement in that the decision rule is simply stated as

If $I(x,y) > T$; then $O(x,y) = 1$
else $O(x,y) = 0$

The threshold T is predecided and globally fixed and is generally in the neighbourhood of the centre value in the tone scale (16 for the test picture of Lincoln). The output process simply generates black and white pixels, depending upon the gray level of the input image at that location. Fig. 3a of Appendix A shows a picture generated by this method. As is obvious, the two ends of the gray scale are reproduced accurately but the remainder are severely distorted. The output picture either has dark or bright areas.

Fine detail which has gray level swings above and below the threshold will be seen. Hence, mid range fine

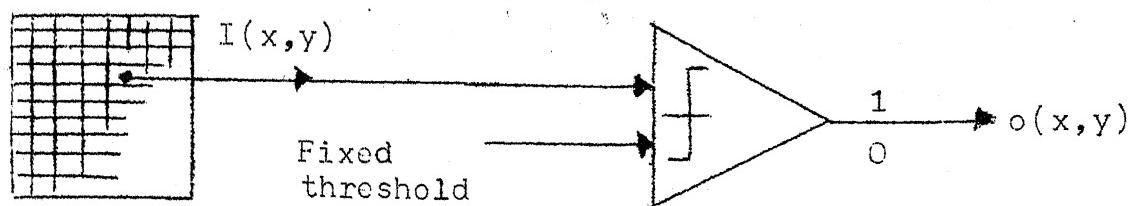


Fig. 3.3 Signal flow diagram for globally fixed threshold

(a)	$\begin{bmatrix} 0 & 14 & 3 & 13 \\ 11 & 5 & 8 & 6 \\ 2 & 12 & 1 & 15 \\ 9 & 7 & 10 & 4 \end{bmatrix}$
-----	--

0	16	4	20	1	17	5	21
24	8	28	12	25	9	29	13
6	22	2	18	7	23	3	19
30	14	26	10	31	15	27	11
1	17	5	21	0	16	4	20
25	9	29	13	24	8	28	12
7	23	3	19	6	22	2	18
31	15	27	11	30	14	26	10

Fig. 3.4 Dither matrices (a) proposed by Lippel and Kurland (b) proposed by Bayer

details is reproduced but the details away from the mid-range are never reproduced. Though the detail rendition is limited to a very small range, very high frequency details are enabled in that range. A high contrast text can be displayed effectively by this technique but not a multi-gray level picture. The processing complexity of this technique is minimum and only one pixel of 'context' is required for the computation.

Fig. 3b of Appendix A shows a picture that has been generated in a slightly different manner. Instead of comparing a pixel of input picture, an average of the pixel and its eight immediate neighbours is calculated and compared to the fixed threshold. As seen, the quality of the output picture still remains the same. The processing complexity of this technique is more as nine pixels of 'context' are required to compute the window average.

3.3.2 Ordered Dither Technique

This technique was worked out for TV signals which being analog had to be quantized before digital transmission and due to the need to reduce the number of bits transmitted, the obvious solution was to reduce the number of quantization steps by increasing the step size. This resulted in the degradation of the TV picture in the areas where intensity changed slowly (i.e. low detail areas). The degradation took the form of 'false contours'. To eliminate

these contours it was suggested to add a pseudo noise signal called a dither signal to the true input signal. This produced rapid switching between the quantizer levels on either side of the true input signal. Pictures were transmitted by using as few as 4 bits/pixel (i.e., 16 gray levels) by Roberts [2] by adding a 2 dimensional pseudo noise sequence. The false contouring in the received picture was reduced by the fact that the subject viewed the picture as a near continuum of gray levels by the eye's averaging over a small two dimensional area.

In the present context the multilevel picture is being quantized into just two levels and one may add a two dimensional pseudo noise sequence to an input prior to quantization to two levels. The resulting picture has the errors distributed spatially and the observer integrates the average reflectance in a small region and sees a near continuum of gray levels. Limb [3], Lippel and Kurland [4] have used it for binary representation. It has been shown subjectively that 'ordered dither patterns' constructed with a small square dither matrix repeated over the picture area to form a rectangular array of matrices is superior to a random arrangement of the same population of samples. Pictures generated by the two kinds of dither have been studied by Lippel and Kurland [4]. They have also studied the arrangement of dither samples in the dither matrix to

find out optimum dither patterns keeping in mind the effect the pattern has on pictorial information in the output picture. The dither patterns suggested by them are given in Fig. 3.4(a). Bayer has also suggested a dither pattern given in Fig. 3.4(b).

This technique thus generates a bilevel representation of continuous tone images by comparing the image values $I(x,y)$ to a position dependant set of thresholds contained in a square dither matrix. This dither matrix is repeated over the entire picture in a checkerboard fashion and the decision for a pixel to be turned bright or dark is

$$\text{If } I(x,y) > D(x,y), \text{ then } O(x,y) = 1 \\ \text{else } O(x,y) = 0$$

Jarvis et al [5] have shown a recursive relationship between the 2×2 matrix of Limb and the matrix generated by Bayer. The Limb's matrix D^2 is one of the four 2×2 matrices that satisfy the Bayer optimization criteria.

$$\text{Given } D^2 = \begin{bmatrix} 0 & 2 \\ 3 & 1 \end{bmatrix} \quad (3.1)$$

and Defining

$$U^n = \begin{bmatrix} 1 & 1 & \dots & 1 \\ 1 & 1 & \dots & 1 \\ \vdots & \vdots & \ddots & \vdots \\ 1 & 1 & \dots & 1 \end{bmatrix} \quad (3.2)$$

The recursive relationship is :

$$D^U = \begin{bmatrix} 4D^{n/2} + D_{00}^2 U^{n/2} & 4D^{n/2} + D_{01}^2 U^{n/2} \\ 4D^{n/2} + D_{10}^2 U^{n/2} & 4D^{n/2} + D_{11}^2 U^{n/2} \end{bmatrix} \quad (3.3)$$

By the first recursion, we get

$$D^4 = \begin{bmatrix} 0 & 8 & 2 & 10 \\ 12 & 4 & 14 & 6 \\ 3 & 11 & 1 & 9 \\ 15 & 7 & 13 & 5 \end{bmatrix} \quad (3.4)$$

This matrix scaled by a factor of 2 to cover the entire range of 32 levels has been used to generate the picture of Fig. 4a and Fig. 4c of Appendix A. Fig. 4a is a 128x128 picture whereas Fig. 4c is a 256x256 picture. Bayer's matrix of Fig. 3.4b has been used to generate the picture of Fig. 4b of Appendix A. The pictures of Figs. 4d, 4e and 4f of Appendix A have been generated using the matrix of (3.4) above but without any scaling to cover the entire range of the tone scale.

This technique results in complete gray level scale generation in the output picture. Comparing pictures of Figs. 4a and 4c of Appendix A with the picture generated by Bayer's matrix (Fig. 4b), it is seen that Bayer's matrix produces more detail. It is due to the entire gray scale range being covered in steps of 1 as compared to the

steps of two for the pictures of Fig. 4a and 4c. The pictures of Figs. 4d, 4e and 4f miss out half the tonal scale due to error in the matrix used. However, picture of 4f gives slightly more detail due to the randomness of the data used.

The processing complexity of this technique is slightly more than the fixed threshold technique as here also only one pixel is processed at a time and instead of a globally fixed threshold it has a look up table for the thresholds.

3.3.3 Constrained Average Technique

This technique developed by Jarvis and Roberts [6] generates one bit for each pixel of input picture $I(x,y)$ by comparing its intensity to a threshold value T computed from $I(x,y)$ and its eight nearest neighbours in the array of the input pixels. If $I(x,y)$ is greater than the threshold T , the corresponding pixel at the output is turned bright. This technique provides edge emphasis alongwith gray scale rendition. The process uses the finite signal to noise ratio inherent in the picture data due to sampling and quantization errors, to generate, on a statistical basis a number of bright cells related to the average image intensity in the picture area.

The threshold is computed as :

$$T = \gamma + \bar{I}(x,y) \left[1 - \frac{2\gamma}{R} \right] \quad (3.5)$$

where $\bar{I}(x,y)$ is the average intensity of $I(x,y)$ and its eight nearest neighbours, R is the highest gray level (31 in the case of the test picture of Lincoln) and γ is a parameter which controls the apparent contrast of the output image and is related to noise statistics. Since $\bar{I}(x,y)$ varies from 0 to R , the threshold changes in the value from γ to $R-\gamma$.

The working of the technique can be explained by the following arguments.

When the average intensity in an area is equal to $R/2$, the threshold value from (3.5) is also equal to $R/2$ and an approximately equal number of pixels will have values above and below the threshold T resulting in one half of the pixels being turned bright. As the brightness increases, the threshold T is less than the average brightness $\bar{I}(x,y)$ resulting in more than one-half of the pixels being turned bright. The reverse happens when the brightness decreases.

The techniques capability of enhancing edges is seen when a pixel markedly different from the local average intensity is considered. The pixel will be turned on or off depending upon its intensity value relative to the neighbourhood average. Pixels near a dark line (edge) will have higher probability of being turned on as the neighbourhood average will be reduced due to the presence of the dark pixels belonging to the line. The reverse will hold good for the pixels on the dark line itself as then the

neighbourhood average would be more than the value of the pixel and it will be turned off. This suggests that the size of the area considered for the computation of the neighbourhood average and the threshold should be small as any step intensity changes or gradients in the area effect the state of the output pixels. Roberts [6] has shown that the constant γ depends upon the noise characteristics of the signal. Thus, a usable value of γ can be obtained if we know the noise characteristics of the signal being processed. In practice, γ may be thought of as an arbitrary parameter that can be specified to obtain a pleasing rendition of the original picture. $\gamma > 0$ results in normal gray scale rendition.

Fig. 3.5 shows a signal flow diagram for the constrained average threshold technique. Figs. 5a to 5e and 6a and 6b of Appendix A show the various pictures generated with different types of data, and different values of γ . As can be seen, edge emphasis has been achieved in all the pictures irrespective of the value of γ or the type of data (repetitive or random) used. For $\gamma = 0$, the picture generated only emphasizes the edges whereas pictures with $\gamma > 0$ render edge emphasis alongwith the gray scales. The control over the apparent contrast of the technique is visible in pictures 5b and 5c. Picture 5c has more contrast than 5b. With $\gamma < 0$, the generated picture is a negative

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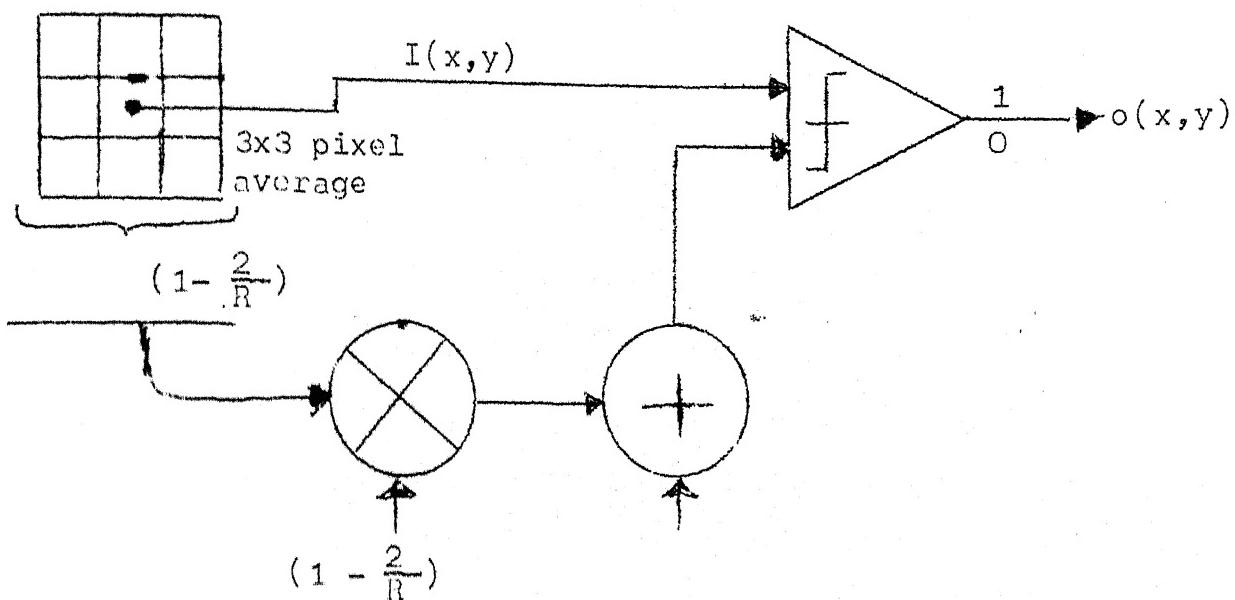


Fig. 3.5 Signal processing flow diagram for constrained Average technique

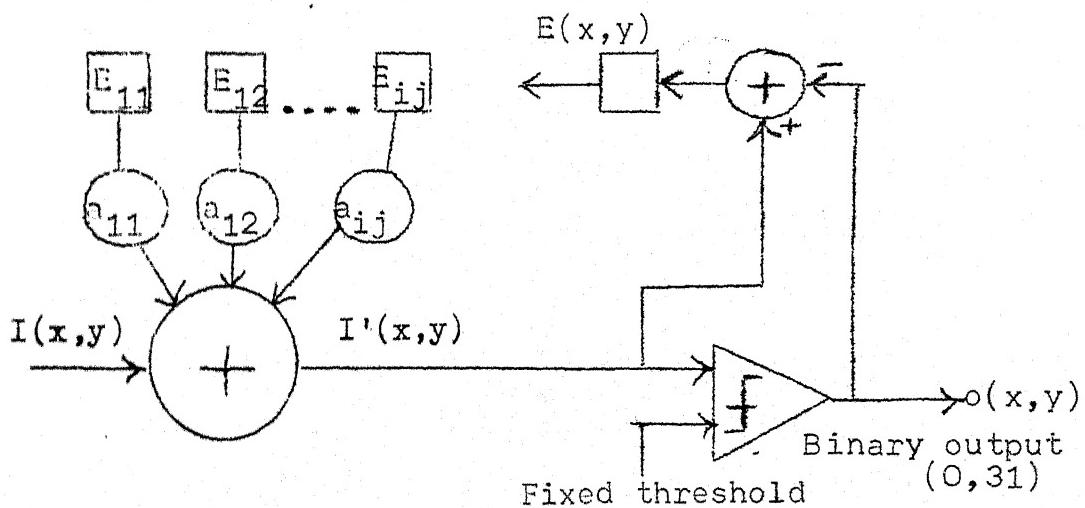


Fig. 3.6a Signal flow diagram for the error diffusion method

$$a_{ij} = \begin{vmatrix} 3 & 6 & 10 & 6 & 3 \\ 6 & 10 & 15 & 10 & 6 \\ 10 & 15 & * & - & - \end{vmatrix}$$

Fig. 3.6(b) The size of the error matrix

like picture but it is not a true negative as the edge enhancement still turns on cells that are more positive than their neighbourhood average. Finally, picture of 5f has been generated by adding a dither signal having rectangular distribution to the data of the picture. This gives the best effects of gray scales and maximum details. The complexity of the constrained Average Technique is more than both the fixed threshold and ordered dither techniques, as a 'context' of 9 pixels is required to compute the neighbourhood average and the technique requires further processing to calculate the threshold.

3.3.4 Error Diffusion Technique

This technique generates local patterns of binary pixels in such a way as to minimize the intensity error between the source and displayed image. When a pixel which was initially gray is turned to bright or dark, it constitutes an error in gray scale. Thus to correct the picture, this gray error is redistributed to nearby pixels, restoring the total gray content to its original value. The original work was presented by Schroeder [7] where the pictures were processed with the help of more than two output states. The technique was used for binary displays by Floyd [8]. Given the gray level of input pixel, the binary decision about the output pixel is made and the error between these two levels is dispersed (diffused) to the

right and below the processed pixel. Fig. 3.6a shows a signal flow diagram representation of the error diffusion technique.

At a point (x,y) in the picture there will be an error between the displayed intensity and the original image which contains more intensity levels than the displayed image.

$$E(x,y) = I(x,y) - O(x,y)$$

where $E(x,y)$ is the intensity error at a point (x,y) , $O(x,y)$ is the displayed intensity and $I(x,y)$ is the original image intensity. To implement the algorithm, a corrected intensity $I'(x,y)$ is computed from the previously computed errors and the intensity $I(x,y)$:

$$I(x,y) = I(x,y) + \sum_{ij} a_{ij} E(i,j)$$

In this equation, the ranges of the indices i and j are defined by the definition of the neighbourhood of point $I(x,y)$. a_{ij} define the weights that multiply the gray scale errors $E(i,j)$ for those pixels prior to the addition of gray scale for $I(x,y)$. Fig. 3.6b gives the neighbourhood of the point (x,y) and the weights a_{ij} that multiply the various $E(i,j)$. The corrected intensity is then compared to a fixed threshold (centre value of the tone scale) to determine whether the corresponding display element should be bright or dark. That is,

If $I'(x,y) > T$: Then $O(x,y) = 1$
 else $O(x,y) = 0.$

Finally the error is computed as

$$E(x,y) = I'(x,y) - O(x,y).$$

The element marked * in Fig. 3.6b is the position of the point $I(x,y)$ under consideration and does not enter into the error computation. Likewise, the elements marked - are ahead of the point (x,y) in the scan line and no error for these elements exists; hence, they can not enter into the error computation. Jarvis et al [5] have shown empirically that the minimum size of the matrix (neighbourhood) needed to generate subjectively satisfactory results is of the order shown in Fig. 3.6b. Hence, the context of this technique is the order of (ij) . In the present case, 'context' is 12, as twelve error values are needed to compute the binary output. The complexity of the technique can also be visualised from the fact that it requires 3 line memories to contain the successive error values and also a substantial number of computations for each pixel are needed, as a weighted sum is required to be done. The boundary handling consists of setting the error values to zero for a boundary two pixels deep on each side and the top of the picture. Only the pixels inside this region are evaluated. This two pixel width boundary is normally not

visible in a 128x128 or higher picture.

This technique, like the ordered dither technique, is capable of reproducing the complete tone scale but the spatial frequencies in the output image will be a function of both the gray level being reproduced and the input image detail. This is due to the effect of the error diffusion to the neighbourhood. For example, the spatial distance between black pixels in a bright area will be very long as compared to that distance for mid-tone gray levels (due to the difference in the quantum of error in the two cases). There may also be a spatial translation in the location of an edge detail depending upon the image content above and to the left of the edge.

This technique is capable of creating output signals which have lower spatial frequencies (as mentioned above) and are thus more visible than in the case of ordered dither technique, which puts a limit on the low frequency response.

Figs. 7a to 7c of Appendix A are the pictures generated by this technique. Picture of 7a is a 64x64 picture whereas the remaining pictures are 128x128. The picture of Fig. 7c has been generated from the random data and hence has more noise as compared to the picture of Fig. 7b which has been generated from the repetitive data.

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CHAPTER IV

CONCLUSION

Electronic manipulation of the pictorial imagery for storage, communication and reproduction often use binary marking/display processes for cost effectiveness. The binary data generated by these processes may be further coded to affect more saving. To illustrate, the picture of Lincoln after being converted to binary bits is Run Length Coded (RLC) and again reproduced. The program used to carry out this processing is named RLC. FOR and is attached at Appendix B. The picture of Lincoln generated by this program is attached as Fig. 10 of Appendix A. The picture is an exact replica of the constrained average picture of Fig. 5b of Appendix A which was taken as the binary picture for coding. The saving effected by the constrained average process was to reduce the data to 1/5th of its original size and the run length coding further affected a saving of slightly less than half.

Though the possibility of displaying pictures with full range of gray scales as a series of on or off cells on a grid of moderate resolution appears marginal, the pictures reproduced in this study show that usable pictures can be displayed in this fashion and hence provide a range

of options to the designer of a visual communication system using bilevel displays.

The processed pictures generated by the various algorithms have been explained in each of the sections/sub-sections under which the algorithms have been discussed. The techniques are evaluated as under :

4.1 EVALUATION OF TECHNIQUES

(a) Orthographic Technique :

The frequency rendition is restricted by the factors of m and n as the binary patterns used are of the size $m \times n$. It is quite common to find false contouring caused due to the binary patterns used. It can be seen to a little extent in the picture of Fig. 2 of Appendix A. It will be more prominent when a higher gray level picture is reproduced by this technique. The output picture also contains a texture depending upon the patterns used. The binary pattern used can easily be seen in the picture of Fig. 2 of Appendix A.

(b) Fixed Threshold Technique :

The frequency rendition of this technique is restricted to only the mid-range gray levels. However, very high frequency fine details are rendered in this range. The black/white boundary in the output picture is an ever present and most common artefact (false contour) to be seen.

Low noise riding the gray levels near the threshold value gets amplified. This low noise may, in fact, be due to the inherent noise characteristics (practical limits on signal to noise factor) of the scanning systems. It may result into a visible artefact which was not present in the original picture.

(c) Ordered Dither :

Due to the checkerboard kind of arrangement of the dither matrix throughout the picture, a limit is placed on the low frequency content of the output. The technique, but for this limit, produces a complete range of frequency and tone scale. The most critical artefact that is seen in this technique is the artificial texture that often accompanies the image. This texture is visible in the dark areas of the coat and bow of Lincoln. To develop an algorithm which gives both high detail rendition and minimum textural visibility is a topic of ongoing research.

(d) Constrained Average Technique :

High frequencies (fine details) are obtained by this algorithms due to its inherent capability of edge enhancement. This detail, though, is at the cost of edge noise. Edges appear more blurred than in the case of fixed threshold due to the use of a neighbourhood average.

(e) Error Diffusion Technique :

This technique produces the complete tonal scale. The spatial frequencies are a function of both the gray level being reproduced and the input image detail. There may be a spatial translation in the location of edge detail depending upon the image content above and to the left of the edge. The technique produces lower frequencies which are more visible than in the case of the ordered dither technique. This effect is clearly visible in the pictures of Figs. 7b and 7c.

The control of the spatial frequencies of the intensity errors by the ordered dither technique provides the best rendition of the complete tonal scale in the original image. This is seen clearly when the dither outputs are compared to the outputs of the other techniques.

Second conclusion reached is that beside the fixed level threshold, the constrained Average Technique due to its inherent edge enhancing capability will make the detail in image consisting of lines and text more visible.

Jarvis et al [1] have made a comparison of the various algorithms and presented it in the form of a picture showing the comparison of the gray scale capabilities of the various techniques. They have reached the conclusion that Ordered Dither besides being a simple technique to implement, also gives the best results, and, perhaps constrained average with dither is a strong contestant to being the best.

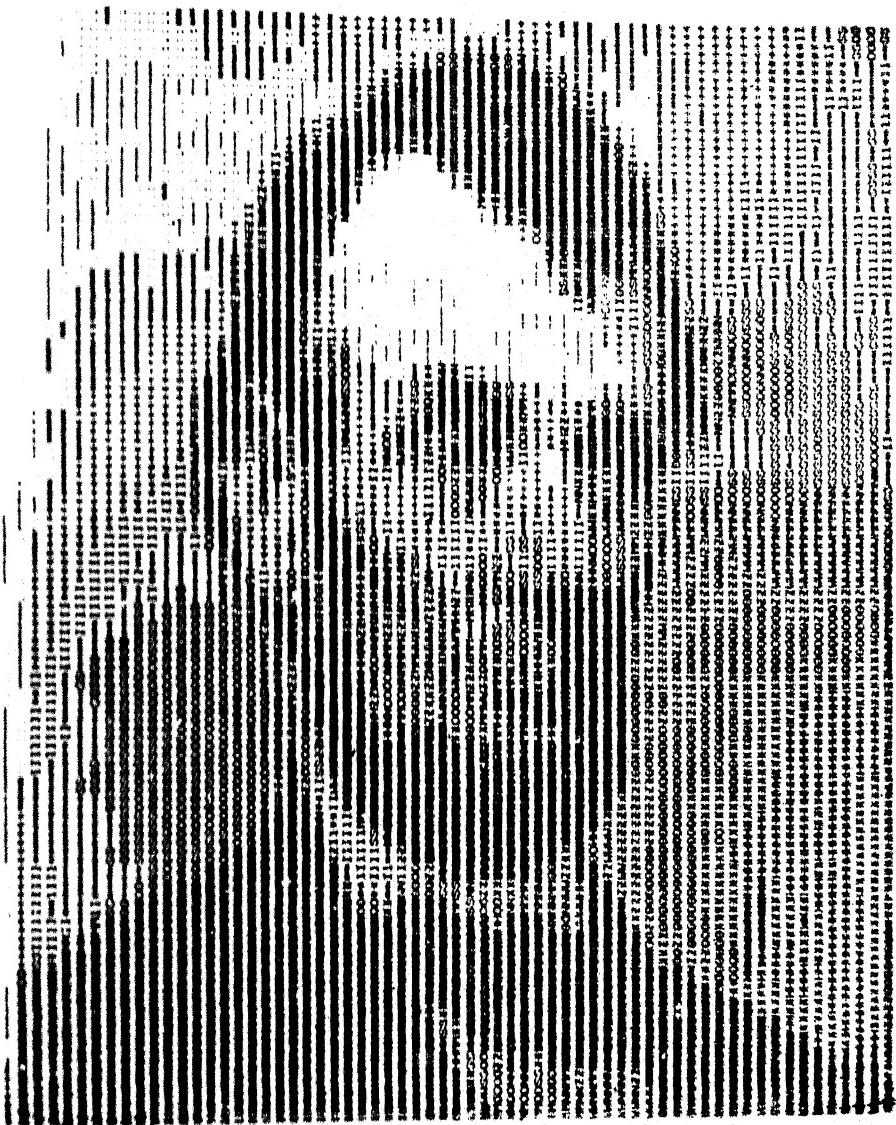
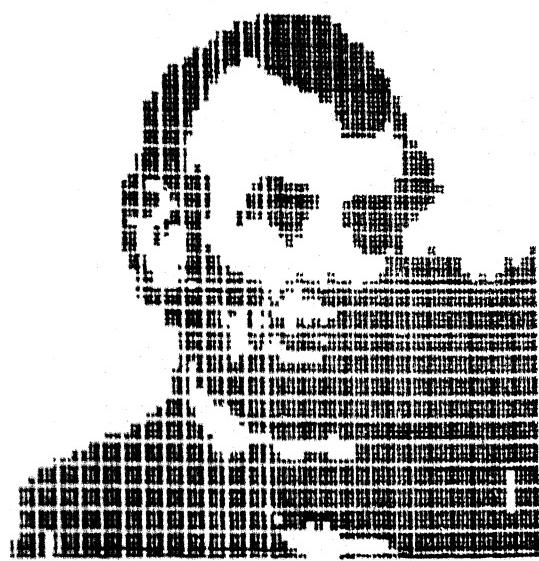


FIG 1: The Test Picture of Lincoln (64x64).



FIG 2: Lithographic Technique using

4x4 Binary Pattern



(a)



(b)

FIG 3: Fixed Threshold Technique.

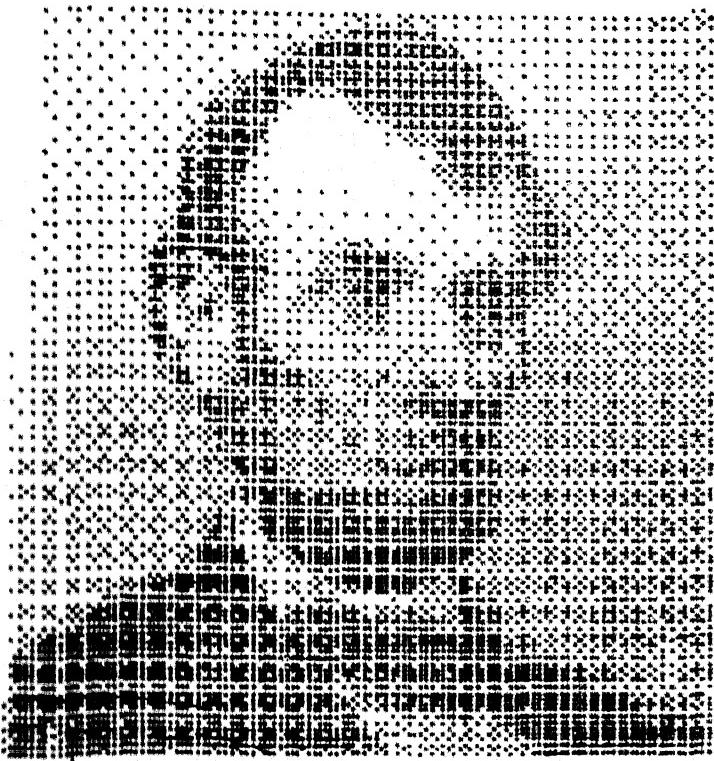


FIG 4(a): Ordered Dither Using 8^4

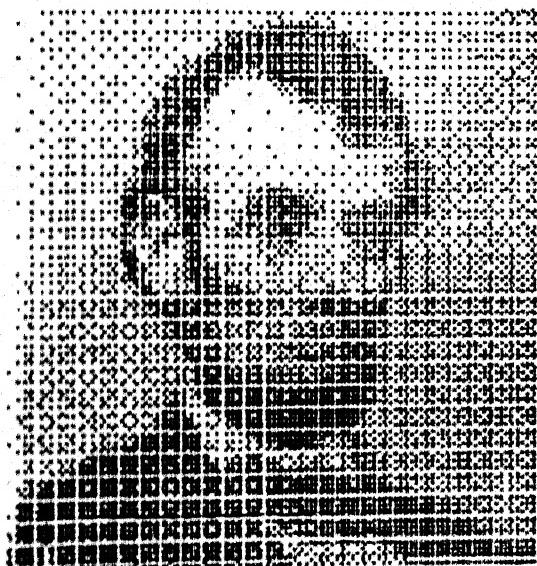


FIG 4(b): Ordered Dither Using
Bayer's Matrix.
(128×128)

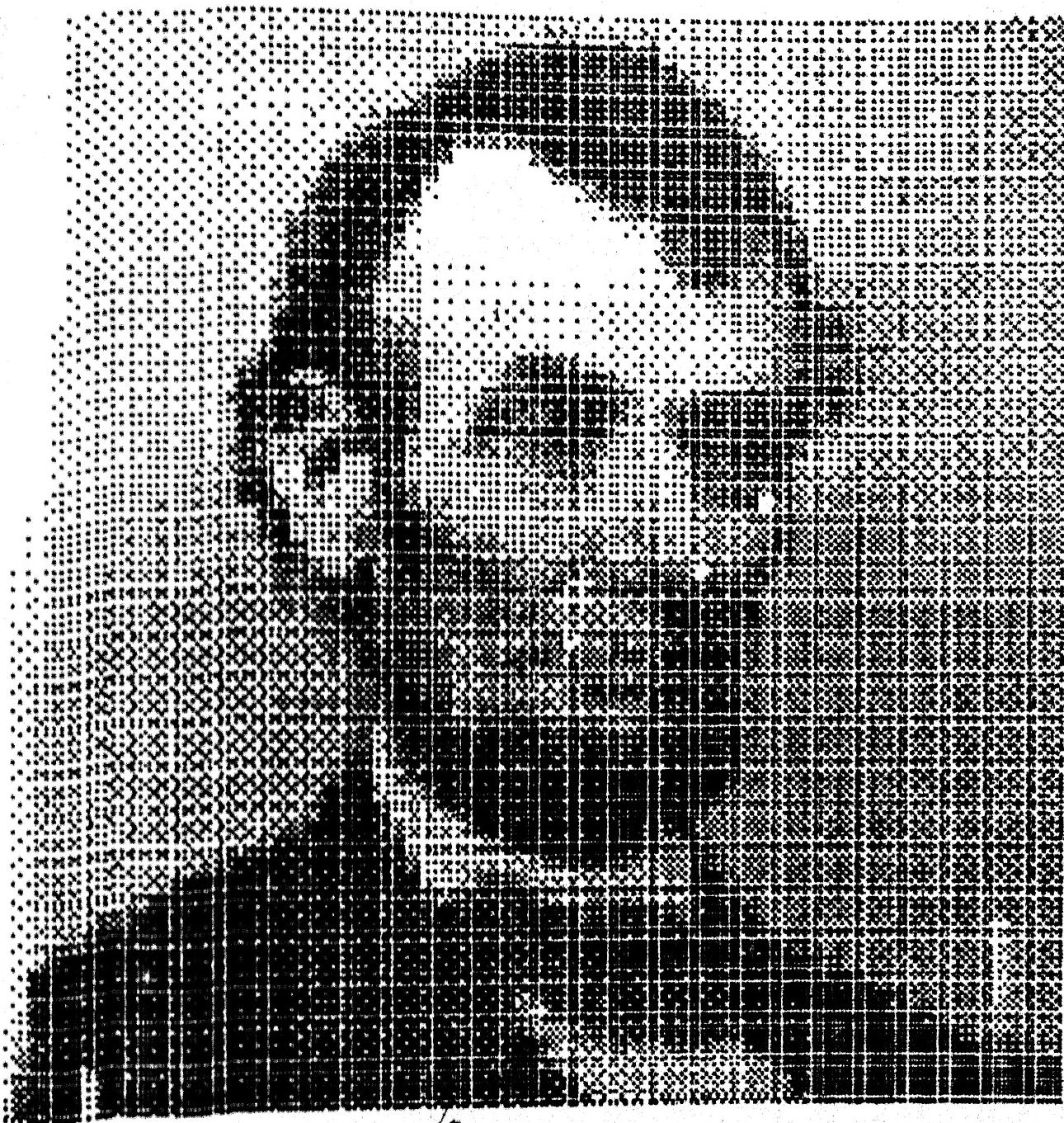


Fig 4(c) - 256x256 Repetitive Data.



FIG 4(d): Ordered Dither Using D^4 With
Half the Range
(256 x 256)



(e)

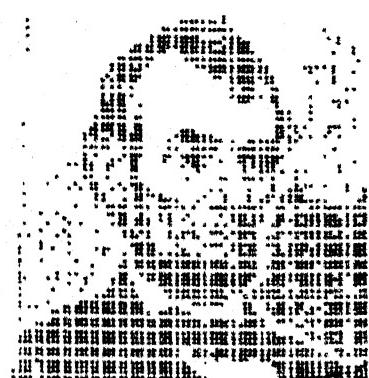


(f)

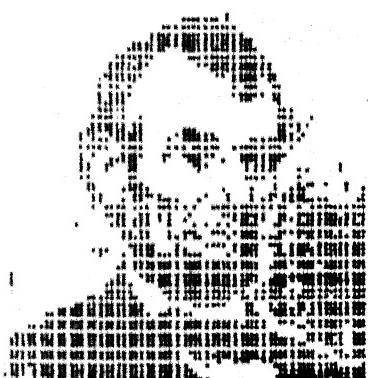
Fig. 4 (contd.) - (e) Repetitive Data (f) Random Data.



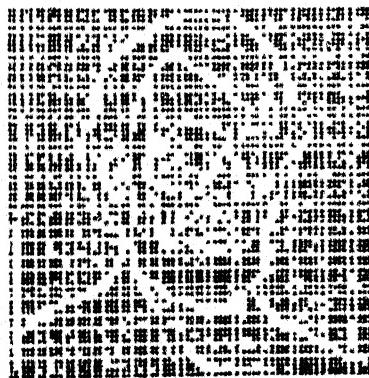
(a) $\gamma = 2$; $X \cdot GE.Y$



(b) $\gamma = 2$; $X \cdot GT.Y$

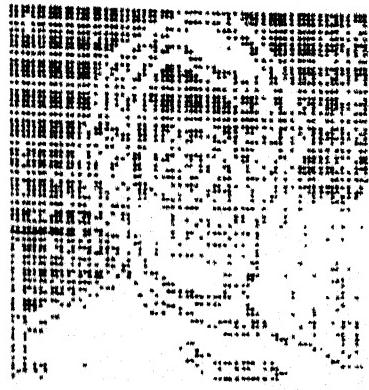


(c) $\gamma = 4$; $X \cdot GT.Y$

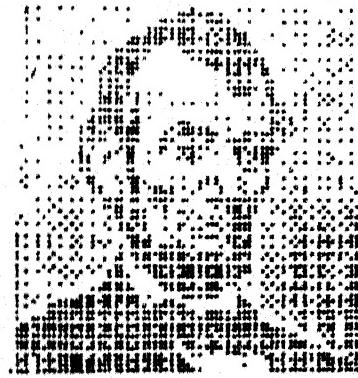


(d) $\gamma = 0$; $X \cdot GT.Y$

FIG 5: Constrained Average Technique
(64×64)



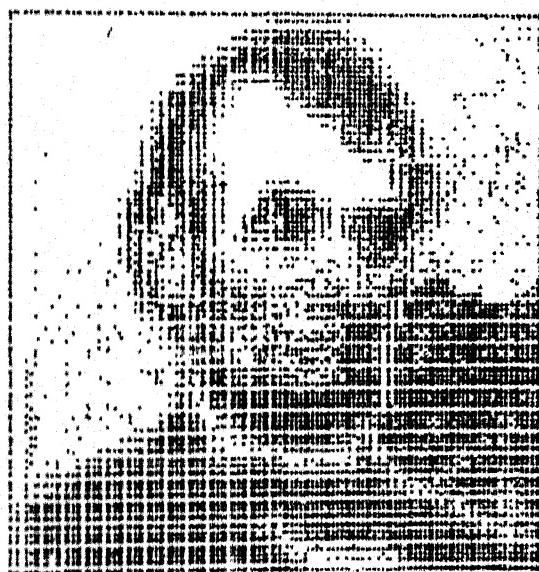
(e) $\gamma = -2$; $X \cdot G \tau Y$



;(contd.) - (f) With Added Dither.

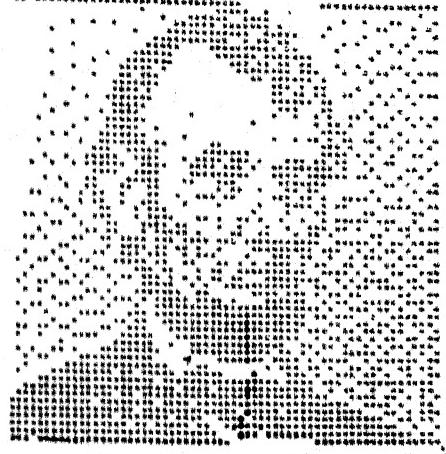


(a) Repeated Data (128x128)

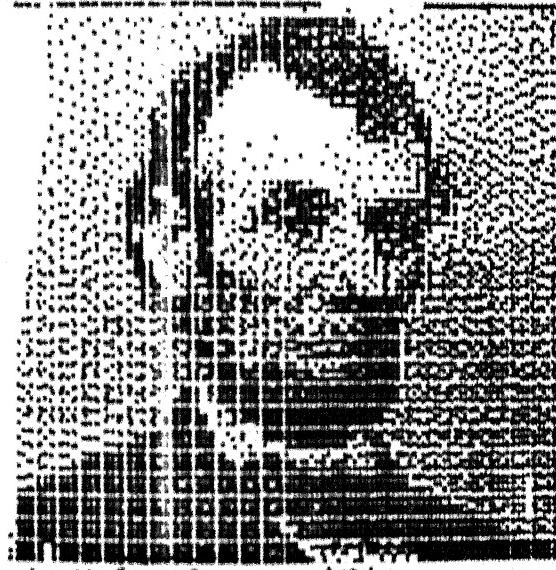


(b) Random Data (128x128)

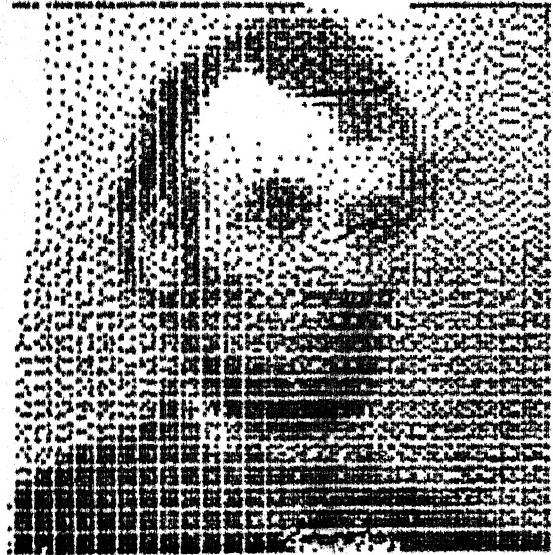
FIG 6: Constrained Average



(a) 64x64



(b) 128x128 Repetitive.



(c) 128x128 Random.

FIG 7: Error Diffusion Technique

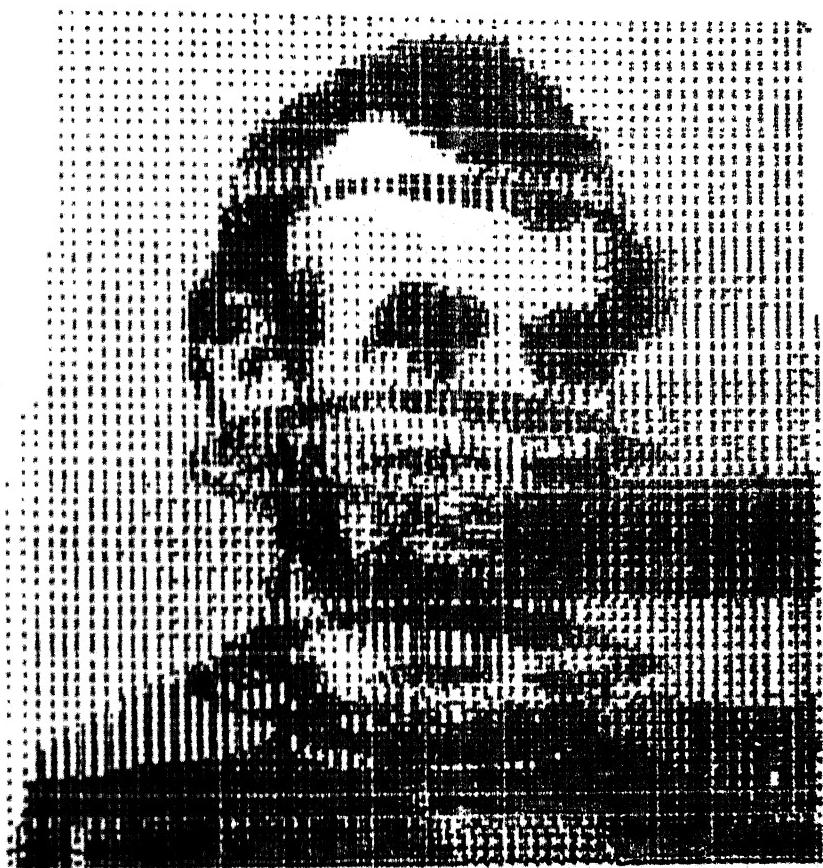


FIG 8: Orthographic Technique



FIG 9: Orthographic Technique Using 6x6 Patterns

Appx B.

```

005600 C PROGRAM DIST.FOR
005700 C *****P*****C
005800 C GAUSS DISTRIBUTION
005900 C NAG G05DOF
010000 C INTEGER A(64,64)
011000 C OPENUNIT#22,DEVICE=DSKD,FILE=IFOR22.DAT")
012000 C OPENUNIT#23,DEVICE=DSKD,FILE=IFOR23.DAT")
013000 C READ (22,*),((A(I,J),J=1,64),I=1,64)
014000 C AVERAGE=0;DEVIATE=0;
015000 C I=1
016000 C DO 50 J=1,5
017000 C DO 51 IREP=1,16
018000 C NRITLE(23,20),A(IR,JT)
019000 S1 COMPUTH3
020000 S0 CONTINUE
021000 C DO 200 I=2,4
022000 C NRITLE(23,20),(A(I,1),K=1,10)
023000 C DO 300 J=2,4
024000 C AVERAGE=FLUAT(A(I-1,J-1)+A(I-1,J)+A(I-1,J+1)+A(I,J-1)+A(I,J))
025000 C 1+A(I,J+1)+A(I+1,J-1)+A(I+1,J)+A(I+1,J+1))/2.+0.5
026000 C DEVIATE=ABS(AVERAGE-FLUAT(A(1,J)))
027000 C ADD 300 CBF(I)
028000 C COUNT=0
029000 10 K=G05DOF(AVERAGE,DEVIATE)
030000 C AVERAGE=AVERAGE
031000 C INTMAX
032000 C IF(INTX.GE.A(1,J)).AND.(INTX.GE.INTAVERAGE))GO TO 450
033000 Z0 PXRAD(10X,15)
034000 S0 IZ=10
035000 450 NRITLE(23,20),INTX
036000 ICOUNT=ICOUNT+1
037000 LBL(200,30,16) GO TO 300
038000 S0 IZ=10
039000 200 COMPUTH3
040000 C NRITLE(23,20),(A(I,10),K=1,10)
041000 200 COMPUTH3
042000 C DEVIATE
043000 C DO 520 JB=1,5
044000 C DO 531 IREP=1,16
045000 C NRITLE(23,20),A(IR,JB)
046000 S3 COMPUTH3
047000 S2 COMPUTH3
048000 STOP
049000 C

```

```
00200  
00300  
00400  
00500      23 PROGRAM FDIST.POR  
00600  
00700      24 DIMENSION A(64,16),B(256)  
00800      25 EQUIVALENCE(A,B)  
00900      26 OPENUNIT=24,DEVICE='DSK01',FILE='FDIST1.DAT'  
01000      27 DD 101=1,64  
01100      28 DD 114=1,64  
01200      29 READ(23,*),(A(I,J),J=1,16)  
01300      30 DD 114=1,64  
01400      31 A(4*(I-1)+J)=A(I,J)  
01500      32 10  
01600      33 11  
01700      34 12  
01800      35 13  
01900      36 14  
02000      37 15  
02100      38 16  
02200      39 17  
02300      40 18  
02400      41 19  
02500      42 20  
02600      43 21  
02700      44 22  
02800      45 23  
02900      46 24  
03000      47 25  
03100      48 26  
03200      49 27  
03300      50 28  
03400      51 29  
03500      52 30  
03600      53 31  
03700      54 32  
03800      55 33  
03900      56 34  
04000      57 35  
04100      58 36  
04200      59 37  
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04400      61 39  
04500      62 40  
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04700      64 42  
04800      65 43  
04900      66 44  
05000      67 45  
05100      68 46  
05200      69 47  
05300      70 48  
05400      71 49  
05500      72 50  
05600      73 51  
05700      74 52  
05800      75 53  
05900      76 54  
06000      77 55  
06100      78 56  
06200      79 57  
06300      80 58  
06400      81 59  
06500      82 60  
06600      83 61  
06700      84 62  
06800      85 63  
06900      86 64  
07000      87 65  
07100      88 66  
07200      89 67  
07300      90 68  
07400      91 69  
07500      92 70  
07600      93 71  
07700      94 72  
07800      95 73  
07900      96 74  
08000      97 75  
08100      98 76  
08200      99 77  
08300      100 78  
08400      101 79  
08500      102 80  
08600      103 81  
08700      104 82  
08800      105 83  
08900      106 84  
09000      107 85  
09100      108 86  
09200      109 87  
09300      110 88  
09400      111 89  
09500      112 90  
09600      113 91  
09700      114 92  
09800      115 93  
09900      116 94  
10000      117 95  
10100      118 96  
10200      119 97  
10300      120 98  
10400      121 99  
10500      122 100  
10600      123 101  
10700      124 102  
10800      125 103  
10900      126 104  
11000      127 105  
11100      128 106  
11200      129 107  
11300      130 108  
11400      131 109  
11500      132 110  
11600      133 111  
11700      134 112  
11800      135 113  
11900      136 114  
12000      137 115  
12100      138 116  
12200      139 117  
12300      140 118  
12400      141 119  
12500      142 120  
12600      143 121  
12700      144 122  
12800      145 123  
12900      146 124  
13000      147 125  
13100      148 126  
13200      149 127  
13300      150 128  
13400      151 129  
13500      152 130  
13600      153 131  
13700      154 132  
13800      155 133  
13900      156 134  
14000      157 135  
14100      158 136  
14200      159 137  
14300      160 138  
14400      161 139  
14500      162 140  
14600      163 141  
14700      164 142  
14800      165 143  
14900      166 144  
15000      167 145  
15100      168 146  
15200      169 147  
15300      170 148  
15400      171 149  
15500      172 150  
15600      173 151  
15700      174 152  
15800      175 153  
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16000      177 155  
16100      178 156  
16200      179 157  
16300      180 158  
16400      181 159  
16500      182 160  
16600      183 161  
16700      184 162  
16800      185 163  
16900      186 164  
17000      187 165  
17100      188 166  
17200      189 167  
17300      190 168  
17400      191 169  
17500      192 170  
17600      193 171  
17700      194 172  
17800      195 173  
17900      196 174  
18000      197 175  
18100      198 176  
18200      199 177  
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18500      202 180  
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18900      206 184  
19000      207 185  
19100      208 186  
19200      209 187  
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19500      212 190  
19600      213 191  
19700      214 192  
19800      215 193  
19900      216 194  
20000      217 195  
20100      218 196  
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20400      221 199  
20500      222 200  
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20700      224 202  
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21000      227 205  
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21200      229 207  
21300      230 208  
21400      231 209  
21500      232 210  
21600      233 211  
21700      234 212  
21800      235 213  
21900      236 214  
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22100      238 216  
22200      239 217  
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22500      242 220  
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22700      244 222  
22800      245 223  
22900      246 224  
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23600      253 231  
23700      254 232  
23800      255 233  
23900      256 234  
24000      257 235  
24100      258 236  
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24500      262 240  
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24900      266 244  
25000      267 245  
25100      268 246  
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25600      273 251  
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25800      275 253  
25900      276 254  
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27300      290 268  
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27900      296 274  
28000      297 275  
28100      298 276  
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28300      300 278  
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28500      302 280  
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30100      318 296  
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33100      348 326  
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41900      436 414  
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50500      522 500  
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50700      524 502  
50800      525 503  
50900      526 504  
51000      527 505  
51100      528 506  
51200      529 507  
51300      530 508  
51400      531 509  
51500      532 510  
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51700      534 512  
51800      535 513  
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52500      542 520  
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52900      546 524  
53000      547 525  
53100      548 526  
53200      549 527  
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53500      552 530  
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53900      556 534  
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54700      564 542  
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55600      573 551  
55700      574 552  
55800      575 553  
55900      576 554  
56000      577 555  
56100      578 556  
56200      579 557  
56300      580 558  
56400      581 559  
56500      582 560  
56600      583 561  
56700      584 562  
56800      585 563  
56900      586 564  
57000      587 565  
57100      588 566  
57200      589 567  
57300      590 568  
57400      591 569  
57500      592 570  
57600      593 571  
57700      594 572  
57800      595 573  
57900      596 574  
58000      597 575  
58100      598 576  
58200      599 577  
58300      600 578  
58400      601 579  
58500      602 580  
58600      603 581  
58700      604 582  
58800      605 583  
58900      606 584  
59000      607 585  
59100      608 586  
59200      609 587  
59300      610 588  
59400      611 589  
59500      612 590  
59600      613 591  
59700      614 592  
59800      615 593  
59900      616 594  
60000      617 595  
60100      618 596  
60200      619 597  
60300      620 598  
60400      621 599  
60500      622 600  
60600      623 601  
60700      624 602  
60800      625 603  
60900      626 604  
61000      627 605  
61100      628 606  
61200      629 607  
61300      630 608  
61400      631 609  
61500      632 610  
61600      633 611  
61700      634 612  
61800      635 613  
61900      636 614  
62000      637 615  
62100      638 616  
62200      639 617  
62300      640 618  
62400      641 619  
62500      642 620  
62600      643 621  
62700      644 622  
62800      645 623  
62900      646 624  
63000      647 625  
63100      648 626  
63200      649 627  
63300      650 628  
63400      651 629  
63500      652 630  
63600      653 631  
63700      654 632  
63800      655 633  
63900      656 634  
64000      657 635  
64100      658 636  
64200      659 637  
64300      660 638  
64400      661 639  
64500      662 640  
64600      663 641  
64700      664 642  
64800      665 643  
64900      666 644  
65000      667 645  
65100      668 646  
65200      669 647  
65300      670 648  
65400      671 649  
65500      672 650  
65600      673 651  
65700      674 652  
65800      675 653  
65900      676 654  
66000      677 655  
66100      678 656  
66200      679 657  
66300      680 658  
66400      681 659  
66500      682 660  
66600      683 661  
66700      684 662  
66800      685 663  
66900      686 664  
67000      687 665  
67100      688 666  
67200      689 667  
67300      690 668  
67400      691 669  
67500      692 670  
67600      693 671  
67700      694 672  
67800      695 673  
67900      696 674  
68000      697 675  
68100      698 676  
68200      699 677  
68300      700 678  
68400      701 679  
68500      702 680  
68600      703 681  
68700      704 682  
68800      705 683  
68900      706 684  
69000      707 685  
69100      708 686  
69200      709 687  
69300      710 688  
69400      711 689  
69500      712 690  
69600      713 691  
69700      714 692  
69800      715 693  
69900      716 694  
70000      717 695  
70100      718 696  
70200      719 697  
70300      720 698  
70400      721 699  
70500      722 700  
70600      723 701  
70700      
```



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0100
0200
0300
0400
0500
0600
0700
0800 C
0900
0100
01100
01200
01300
01400
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01600
01700
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06100 101
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08300
08400
08500
08600
08700
08800
DIMENSION X(25),Y(25),XP(25),YP(25),TEMP(25),W(6),V(6),Z(25)
INTEGER TTY
DATA TTY/7/,W/-2.0,-6.0,0,0,0,8.0,-2.0,6.0/
DATA VZ/0.0,1.0,0.0,1.0,0.0,0,1.0/
CALL NITDEV(TTY)
CALL IDEN
CALL WINDOW(W(1))
CALL VPORT(V(1))
CALL CLICTL(1)
DO SL=1,18
READ(29,*),((X(I),Y(I),Z(I)),I=1,5)
NES
SLP1=30
SLPN=330.
Z1=Z(1)
CALL ROTAD(20.0,2)
CALL ROTAD(20.0,1)
CALL LINE3(X(1),Y(1),Z1,0)
WRITE(24,*),X(1),Y(1),Z1
CALL IDEN
S=0.;SIGMA=0.1
CALL KURV1(N,X,Y,SLP1,SLPN,XP,YP,TEMP,S,SIGMA)
T11=0.01;XS=0;YS=0;
DO 100 IJ=1,100
IF(IJ.GT.1)T11=-T11
T=T11*FLOAT(IJ)
CALL KURV2(T,XS,YS,N,X,Y,XP,YP,S,SIGMA)
IF(IJ-(IJ/2)*2.NE.0)GO TO 100
CALL ROTAD(20.0,2)
CALL ROTAD(20.0,1)
CALL LINE3(XS,YS,Z1,1)
WRITE(24,*),XS,YS,Z1
CALL IDEN
CONTINUE
35000 5
CONTINUE
03700
03800
03900
04000
04100
04200
04300
04400
04500
04600
04700
04800
04900
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05100
05200
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07400
07500
07600
07700
07800
07900
08000
08100
08200
08300
08400
08500
08600
08700
08800
101 6
ACCEPT*,OK
STOP
END
THIS SUBROUTINE DETERMINES THE PARAMETERS NECESSARY TO
COMPUTE A SPLINE UNDER TENSION PASSING THROUGH A SEQUENCE
OF PAIRS (X(1),Y(1),-----,X(N),Y(N)) IN THE PLANE. THE
SLOPES AT THE TWO ENDS OF THE CURVE MAY BE SPECIFIED OR
 OMITTED. FOR ACTUAL COMPUTATION OF POINTS ON THE CURVE IT
 IS NECESSARY TO CALL THE SUBROUTINE KURV2.
ON INPUT -----
N IS THE NUMBER OF POINTS TO BE INTERPOLATED (N.GE.2)
X IS AN ARRAY CONTAINING THE N X-COORDINATES OF THE
POINTS
Y IS AN ARRAY CONTAINING THE N Y-COORDINATES OF THE
POINTS.
SLP1 AND SLPN CONTAIN THE DESIRED VALUES FOR THE SLOPES
OF THE CURVE AT (X(1),Y(1)) AND (X(N),Y(N)), RESPECTIVELY.
THESE QUANTITIES ARE IN DEGREES AND MEASURED COUNTER-
CLOCKWISE FROM THE POSITIVE X-AXIS. THE POSITIVE SENSE
OF THE CURVE IS ASSUMED TO BE THAT MOVING FROM THE
POINT 1 TO POINT N. IF THE QUANTITY SIGMA IS NEGATIVE
THESE SLOPES WILL BE DETERMINED INTERNALLY AND THE USER
NEED ONLY FURNISH PLACE-HOLDING PARAMETERS FOR SLP1
AND SLPN. SUCH PLACE HOLDING PARAMETERS WILL BE IGNORED
BUT NOT DESTROYED.
XP AND YP ARE ARRAYS OF LENGTH AT LEAST N

```

09000
 09100
 09200
 09300
 09400
 09500
 09600
 09700
 09800
 09900
 10000
 10100
 10200
 10300
 10400
 10500
 10600
 10700
 10800
 10900
 11000
 11100
 11200
 11300
 11400
 11500
 11600
 11700
 11800 C
 11900
 12000
 12100 C
 12150 C
 12175 C
 12200 10
 12300
 12400
 12500
 12600
 12700
 12800
 12900
 13000
 13100
 13200
 13300
 13400
 13500
 13600
 13700
 13800
 13900
 14000
 14100
 14200
 14250 C
 14300 20
 14400 30
 14500
 14600 C
 14650 C
 14700 C
 14750 C
 14800
 14900
 15000
 15100
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 15400
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 15900
 16000
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 17200

SEARCH STORAGE,
 AND
 SIGMA CONTAINS THE TENSION FACTOR. THIS IS NON ZERO AND
 INDICATES THE CURVINESS DESIRED. IF ABS(SIGMA) IS VERY
 LARGE(E.G.50) THE RESULTING CURVE IS VERY NEARLY A
 POLYGONAL LINE. THE SIGN OF SIGMA INDICATES WHETHER
 SLOPE INFORMATION HAS BEEN INPUT OR NOT. IF SIGMA IS
 NEGATIVE THE END POINT SLOPES WILL BE DETERMINED
 INTERNALLY. A STANDARD VALUE FOR SIGMA IS APPROXIMATELY
 1. IN ABSOLUTE VALUE.
 ON OUTPUT-----
 N, X, Y, SLP1, SLPN AND SIGMA ARE UNALTERED.
 XP AND YP CONTAIN INFORMATION ABOUT THE CURVATURE OF THE
 CURVE AT GIVEN NODES,
 AND
 S CONTAINS THE POLYGONAL ARC LENGTH OF THE CURVE.
 → SUBROUTINE KURV1(N,X,Y,SLP1,SLPN,XP,YP,TEMP,S,SIGMA)
 INTEGER N
 REAL X(N),Y(N),XP(N),YP(N),TEMP(N),S,SIGMA
 DEGRAD = 3.1459265/180.
 NM1=N-1
 NP1=N+1
 DELX1=X(2)-X(1)
 DELY1=Y(2)-Y(1)
 DELS1=SQRT(DELX1*DELX1+DELY1*DELY1)
 DX1=DELX1/DELS1
 DY1=DELY1/DELS1
 DETERMINE SLOPES IF NECESSARY
 IF (SIGMA.LT.0.) GO TO 70
 SLPP1=SLP1*DEGRAD
 SLPPN=SLP1*DEGRAD
 SET UP RIGHT HAND SIDES OF TRIDIAGONAL LINEAR SYSTEM
 FOR XP AND YP
 XP(1)=DX1-COS(SLPP1)
 YP(1)=DY1-SIN(SLPP1)
 TEMP(1)=DELS1
 S=DELS1
 TF(N.EQ.2) GO TO 30
 DO 20 I=2,NM1
 DELX2=X(I+1)-X(I)
 DELY2=Y(I+1)-Y(I)
 DELS2=SQRT(DELX2*DELX2+DELY2*DELY2)
 DX2=DELX2/DELS2
 DY2=DELY2/DELS2
 XP(1)=DX2-DX1
 YP(1)=DY2-DY1
 TEMP(1)=DELS2
 DELX1=DELX2
 DELY1=DELY2
 DELS1=DELS2
 DX1=DX2
 DY1=DY2
 ACCUMULATE POLYGONAL ARCLENGTH
 S=S+DELS1
 CONTINUE
 XP(N)=COS(SLPPN)-DX1
 YP(N)=SIN(SLPPN)-DY1
 DENORMALISE TENSION FACTOR
 SIGMAP=ABS(SIGMA)*FLOAT(N-1)/S
 PERFORM FORWARD ELIMINATION ON TRIDIAGONAL SYSTEM
 DELS=SIGMAP*TEMP(1)
 EXPS=EXP(DELS)
 SINHS=0.5*(EXPS-1./EXPS)
 SINHIN=1./(TEMP(1)*SINHS)
 DIAG1=SINHIN*(DELS*0.5*(EXPS+1./EXPS)-SINHS)
 DIAGIN=1./DIAG1
 XP(1)=DIAGIN*XP(1)
 YP(1)=DIAGIN*YP(1)
 SPDIA=SPDIAG*(SINHS-DELS)
 TEMP(1)=DIAGIN*SPDIA
 TF(N.EQ.2) GO TO 50
 DO 40 I=2,NM1
 DELS=SIGMAP*TEMP(I)
 EXPS=EXP(DELS)
 SINHS=0.5*(EXPS-1./EXPS)
 SINHIN=1./(TEMP(I)*SINHS)
 DIAG2=SINHIN*(DELS*0.5*(EXPS+1./EXPS)-SINHS)
 DIAGIN=1./((DIAG1+TAG2-SPDIA)*TEMP(I-1))
 XP(I)=DIAGIN*(XP(I)-SPDIA*XP(I-1))
 YP(I)=DIAGIN*(YP(I)-SPDIA*YP(I-1))
 SPDIA=SINHIN*(SINHS-DELS)
 TEMP(I)=DIAGIN*SPDIA
 DIAG1=DIAG2
 CONTINUE
 DATA NM1=1/(DIAG1-SPDIA*TEMP(NM1))

```

17400      YP(N)=DIAGIN*(YP(N)-SPDIAG*YP(NM1))
17450      C
17500      PERFORM BACK SUBSTITUTION
17600      DO 50 I=2,N
17650      IBAK=NPI-I
17700      XP(IBAK)=XP(IBAK)-TEMP(IBAK)*XP(IBAK+1)
17800      YP(IBAK)=YP(IBAK)-TEMP(IBAK)*YP(IBAK+1)
17900
18000      60 CONTINUE
18100      RETURN
18200      70 IF(N.EQ.2) GO TO 80
18250      CC IF NO SLOPES ARE GIVEN, USE SECOND ORDER INTERPOLATION ON
18275      INPUT DATA FOR SLOPES AT END POINTS
18300      DELS2=SORT((X(3)-X(2))**2+(Y(3)-Y(2))**2)
18400      DELS12=DELS1+DELS2
18500      C1=- (DELS12+DELS1)/DELS12/DELS1
18600      C2=DELS12/DELS1/DELS2
18700      C3=-DELS1/DELS12/DELS2
18800      SX=C1*X(1)+C2*X(2)+C3*X(3)
18900      SY=C1*Y(1)+C2*Y(2)+C3*Y(3)
19000      SLPP1=ATAN2(SY,SX)
19100      DELNM1=SORT((X(N-2)-X(NM1))**2+(Y(N-2)-Y(NM1))**2)
19200      DELN=SORT((X(NM1)-X(N))**2+(Y(NM1)-Y(N))**2)
19300
19400      DELNN=DELNM1+DELN
19500      C1=(DELN+DELN)/DELNN/DELN
19600      C2=-DELN/DELN/DELN
19700      C3=DELN/DELN/DELN
19800      SX=CB3*X(N-2)+C2*X(NM1)+C1*X(N)
19900      SY=CB3*Y(N-2)+C2*Y(NM1)+C1*Y(N)
20000      SLPPN=ATAN2(SY,SX)
20100      GO TO 10
20150      CC IF ONLY TWO POINTS AND NO SLOPES ARE GIVEN, USE STRAIGHT
20175      LINE SEGMENT FOR CURVE
20200      80 XP(1)=0.
20300      XP(2)=0.
20400      YP(1)=0.
20500      YP(2)=0.
20600      RETURN
20700      END
20710      THIS SUBROUTINE PERFORMS THE MAPPING OF POINTS IN THE
20712      INTERVAL OF (0.,1.) ONTO A CURVE IN THE PLANE. THE SUB-
20714      ROUTINE KURV1 SHOULD BE CALLED EARLIER TO DETERMINE
20716      CERTAIN NECESSARY PARAMETERS. THE RESULTING CURVE HAS
20718      A PARAMETRIC REPRESENTATION BOTH OF WHOSE COMPONENTS
20720      ARE SPLINE UNDER TENSION AND FUNCTIONS OF THE POLYGON-
20722      AL ARCLENGTH PARAMETER.
20724      ON INPUT -----
20726      T CONTAINS A REAL VALUE OF ABSOLUTE VALUE LESS THAN OR
20728      EQUAL TO 1. TO BE MAPPED TO A POINT ON THE CURVE. THE
20730      SIGN OF T IS IGNORED AND THE INTERVAL (0.,1.) IS MAPPED
20732      ONTO THE ENTIRE CURVE. IF T IS NEGATIVE THIS INDICATES
20734      THAT THE SUBROUTINE HAS BEEN CALLED PREVIOUSLY (WITH ALL
20736      OTHER INPUT VARIABLES UNALTERED) AND THAT THIS VALUE OF
20738      T EXCEEDS THE PREVIOUS VALUE IN ABSOLUTE VALUE. WITH
20740      SUCH INFORMATION THE SUBROUTINE IS ABLE TO MAP THE POINT
20742      MUCH MORE RAPIDLY. THUS IF THE USER SEEKS TO MAP A
20744      SEQUENCE OF POINTS ON TO THE SAME CURVE, EFFICIENCY IS
20746      GAINED BY ORDERING THE VALUES INCREASING IN MAGNITUDE
20748      AND SETTING THE SIGN OF ALL BUT THE FIRST NEGATIVE
20750      N CONTAINS THE NUMBER OF POINTS WHICH WERE INTERPOLATED
20752      TO DETERMINE THE CURVE.
20754      X AND Y ARE ARRAYS CONTAINING THE X- AND Y-COORDINATES
20756      OF THE INTERPOLATED POINTS.
20758      XP AND YP ARE THE ARRAYS OUTPUT FROM KURV2 CONTAINING
20760      CURVATURE INFORMATION.
20762      S CONTAINS THE POLYGONAL ARCLENGTH OF THE CURVE.
20764      SIGMA CONTAINS THE TENSION FACTOR (ITS SIGN IS IGNORED).
20766      THE PARAMETERS N,X,Y,XP,YP,S AND SIGMA SHOULD BE INPUT
20768      UNALTERED FROM THE OUTPUT OF KURV1.
20770      ON OUTPUT -----
20772      XS AND YS CONTAIN THE X- AND Y-COORDINATES OF THE IMAGE
20774      POINT ON THE CURVE.
20776      T,N,X,Y,XP,YP,S AND SIGMA ARE UNALTERED
20778      C DENDRORMALIZE SIGMA
20780      SUBROUTINE KURV2(T,XS,YS,N,X,Y,XP,YP,S,STGMA)
20782      INTEGER N
20784      REAL T,XS,YS,X(N),Y(N),XP(N),YP(N),S,STGMA
20786      SIGMAP=ABS(SIGMA)*FLOAT(N-1)/S
20788      STRETCH UNIT INTERVAL INTO ARC LENGTH DISTANCE
20790      TN=ABS(T*S)
20792      C FOR NEGATIVE T START SEARCH WHERE PREVIOUSLY TERMINATED
20794      OTHERWISE START FROM BEGINNING
20796      IF(T.LT.0.) GO TO 10
20798      T1=2
20800      XS=X(1)
20802      YS=Y(1)
20804      SUM=0.
20806      T1=T-E(0.) RETURN

```

```

21950      C      DETERMINE INTO WHICH SEGMENT TN IS MAPPED
22000      DO 30 I=1,N
22100      DELX=X(I)-X(I-1)
22200      DELY=Y(I)-Y(I-1)
22300      DELS=SORT(DELX*DELX+DELY*DELY)
22400      IF(SUM+DELS-TN) 20,40,40
22500      20      SUM=SUM+DELS
22600      30      CONTINUE
22650      C      IF ABS(T) IS GREATER THAN 1., RETURN TERMINAL
22675      POINT ON CURVE
22700      XS=X(N)
22800      YS=Y(N)
22900      RETURN
22950      C      40      SET UP AND PERFORM INTERPOLATION
23000      DEL1=TN-SUM
23100      DEL2=DELS-DEL1
23200      EXPSS1=EXP(SIGMAP*DEL1)
23300      SINHD1=0.5*(EXPS1-1./EXPS1)
23400      EXPSS=EXP(SIGMAP*DEL2)
23500      SINHD2=0.5*(EXPS-1./EXPS)
23600      EXPSS=EXPS1*EXPS
23700      SINHSE=0.5*(EXPS-1./EXPS)
23800      XS=(XP(I)*SINHD1+XP(I-1)*SINHD2)/SINHS
23900      1+((X(I)-XP(I))*DEL1+(X(I-1)-XP(I-1))*DEL2)/DELS
24000      YS=(YP(I)*SINHD1+YP(I-1)*SINHD2)/SINHS
24100      1+((Y(I)-YP(I))*DEL1+(Y(I-1)-YP(I-1))*DEL2)/DELS
24200      I1=I
24300      RETURN
24400      END
24450      C      THIS SUBROUTINE PERFORMS THE MATRIX MULTIPLICATION
24475      OF A AND B MATRICES TO GIVE C MATRIX AS THE RESULT
24500      →      SUBROUTINE MATMUL (A,B,C)
24600      DIMENSION A(4,4),B(4,4),C(4,4)
24700      DO 10 I=1,4
24800      DO 10 J=1,4
24900      C(I,J)=0.0
25000      DO 10 K=1,4
25100      C(I,J)=C(I,J)+A(I,K)*B(K,J)
25200      10      CONTINUE
25300      RETURN
25400      END
25500      →      SUBROUTINE MATPRI(P)
25600      DIMENSION P(4,4)
25700      WRITE(23,10),((P(I,J),J=1,4),I=1,4)
25800
25900      10      FORMAT(4F16.10)
26000      RETURN
26100      END

```

```

00017 C This program generates a crosshatched figure,
00027 C that is, one figure whose lines run parallel to the X-axis
00037 C overlaid by another figure whose lines run parallel to the
00047 C Z-axis.
00057 C
00067 C DIMENSION MASK(2000), VERTEX(20), OUTBUF(51), Z(51), X(51)
00077 C DIMENSION X(4), X1(50,51), Y1(50,51), Z1(50,51)
00087 C DATA X/0.0,1000.0,0.0,1000.0/
00097 C CALL NIDEV(7)
00107 C ADDIND(0)
00117 C First figure
00127 C Generate data running parallel to X-axis
00137 C DO 1 I=1,29
00147 C DO 1 J=1,51
00157 C READ(22,*),X1(I,J),Y1(I,J),Z1(I,J)
00167 C CONTINUE
00177 C
00187 C DO 20 NLINE = 1, 29
00197 C     DO 10 NPOINT = 1, 51
00207 C XNPPOINT=X1(30-NLINE,NPOINT)
00217 C OUTBUF(NPDTNT)=X1(30-NLINE,NPOINT)
00227 C ZNPPOINT=Z1(30-NLINE,NPOINT)
00237 C
00247 C CONTINUE
00257 C Plot each line as it is computed
00267 C CALL PLOT3D(1111,X,OUTBUF,Z,0.2,0.2,0.2,
00277 C 15,51,-20.0,-20.0,0.0,5.0,10.0,MASK,0)
00287 C
00297 C 20
00307 C
00317 C Second figure
00327 C Generate data running parallel to Z-axis
00337 C DO 50 NCINES=1,29
00347 C     DO 40 NPPOINT=1, 51
00357 C     READ(23,*),X(52-NPOINT),OUTBUF(52-NPOINT),Z(52-NPOINT)
00367 C     CONTINUE
00377 C Plot each line as it is computed
00387 C     CALL PLOT3D(1111,X,OUTBUF,Z,0.0,0.2,0.2,
00397 C 15,51,-20.0,-20.0,0.0,5.0,10.0,MASK,VERTEX)
00407 C
00417 C CONTINUE
00427 C Draw a frame on the figure.
00437 C     CALL FRAME( 3, VERTEX, MASK )
00447 C ACCEPT*,OKI
00457 C STOP; END

```

1 XSCALE, ZSCALE, NLINE, NPNTS, PHI, THETA, XREF,
 2 YREF, XLENTH, MASK, VERTEX)
 Masked 3-Dimensional plot program with rotations
 This routine will accept 3-Dimensional data in various
 forms as input, rotate in 3-space to any angle
 and plot the projection of the resulting figure onto the
 XY-plane. Linear interpolation is used between data points.
 Those lines of a figure which should be hidden by a previous
 line are masked.
 The masking techniques used by this routine is based on
 two premises -
 Lines in the fore-ground (positive Z-direction)
 are plotted before lines in the background.
 A line or a portion of a line is masked (hidden) if
 it lies within the region bounded by previously
 plotted lines.
 Each call to PLOT3D causes one line of a figure to be plotted.
 Two parameters of the plotter are set on the initial call
 for each figure -
 (PIP1) is the number of plotter increments per inch.
 (NKPI) is the number of increments available across the
 width of the paper (Y-direction).
 When a new figure is initiated, the plotter origin is set
 at the bottom of the paper by PLOT3D and should not be
 moved until the figure is completed.
 Input parameters -
 (IVXYZ) is a four digit decimal integer which is used
 to select various input/output options. These digits in
 decreasing order of magnitude, will be referred to as V,
 X, Y, and Z.
 If V.NE.0, the verticies of the current figure and their
 projection on to the Y = 0 plane, will be stored in a 16
 entry real array (VERTEX) and will be updated as each
 line is plotted. These co-ordinates are in inches and
 relative to the current plotter origin. The X-Y pairs
 are ordered so that first pair corresponds to the
 first point of the figure, the second pair corresponds to
 the last point of the first line, and the following
 pairs are ordered in a circular fashion. The pairs on the
 Y = 0 plane of the figure, then follow in the same order.
 If V = 0, the VERTEX parameter is ignored, but should not be
 deleted.
 If X = 0, the X-components of this line are assumed to be
 equally spaced, and are computed by
 X(I) = XDATA(1) + (I-1) * XSCALE
 where (XDATA) is the initial value in inches and (XSCALE)
 is the spacing between points in inches. If X.NE.0, the
 X-components of this line are read from an array and
 modified by
 X(I) = XDATA(I) * XSCALE
 where XSCALE is a scale factor.
 The same relations hold for the Y-components, i.e., if
 Y = 0
 Y(I) = YDATA(1) + (I-1) * YSCALE
 and if Y.NE.0
 Y(I) = YDATA(I) * YSCALE
 If Z = 0, the Z-components of this line are all assumed to
 be equal, and are computed by
 Z(I) = ZDATA(1) + (NLINE-1) * ZSCALE
 where (NLINE) is some integer associated with this line.
 If Z.NE.0, again we have
 Z(I) = ZDATA(I) * ZSCALE
 when (NLINE) is equal to one, it indicates the beginning
 of a new figure. A call to PLOT3D with (NLINE) equal to
 zero before initiating a new figure simulates a line drawn
 at the bottom of the page. Therefore only those portions
 of a line lying above all previous lines will be plotted.
 all other parameters are ignored on such a call.
 (NPNTS) is the number of points on this line and may be
 altered from line to line.
 (PHI) and (THETA) are the two angles (in degrees) used to
 specify the desired 3-dimensional rotations. The following
 two definitions of these rotations are equivalent -
 in terms of rotations of axes, the initial system of axes,
 XYZ, is rotated by an angle (PHI) counter-clockwise about
 the Y-axis, and the resultant system is labelled to TUV
 axes. The TUV axes are then rotated by an angle (THETA)
 counter-clockwise about the T-axis, and this final system
 is labelled the PQR-axes. The plotted figure is the
 projection of the original figure onto the PQ-plane.
 In terms of rotations of co-ordinates, the figure is first
 rotated by an angle (THETA) clockwise about the X-axis.
 The resultant figure is then rotated by an angle (PHI)
 clockwise about its Y-axis. The plotted figure is the
 projection of this final figure on to the XY-plane.
 Warning:
 Some rotations will alter the fore-ground/background
 relationships bet. sen the lines, and thus the order

('XREF') and ('YREF') are the co-ordinates in inches, relative to the plotter origin, to be used as the origin of the figure.
 (XLENTH) is the length, in inches, to which the plot is restricted. Any points which exceeds this limit, or the limits of the paper in the Y-direction (NYPI) will be set to that limit.
 (MASK) is an integer array of $2 * \text{XLENTH} * \text{PIPI}$ entries which is used to store the MASK. The contents of this array should not be altered during the plotting of any given figure.
 All parameters except (MASK) and (VERTEX) are returned unchanged.
 Between any two calls for the same figure, any parameter can be meaningfully changed except (XLENTH), (MASK), and (VERTEX).
 INTEGER HIGH, OLDDHI, OLDLOW
 DIMENSION XDATA(1), YDATA(1), ZDATA(1), MASK(1),
 VERTEX(1)
 DATA INIT, JVXYZ, SPHI, STHETA/ -1, -1, -1.0E35, -1.0E35 /
 Initialization procedures
 Initialization procedure for a new figure
 Test for special MASK modifying call
 IF(NLINE.EQ.0) GOTO 550
 Determine if initialization is required
 IF(NLINE.NE.1) GOTO 20
 Set plotter parameters
 PIPI = 100.0
 NYPI = 1090
 Reset plotter origin to bottom of plot page
 I = NYPI+100
 CALL IP60T(0, 0, 3)
 Compute length of plot page in increments
 LIMITX = XLENTH*PIPI + 0.5
 I = LIMITX + LIMITX
 Initialize masking array over the length of the plot page
 DO 10 K=1,I
 MASK(K) = INIT
 CONTINUE
 INIT = -1
 Set the necessary indicators for the first line of a new figure
 INCI = -1; I = 0
 Input type and VERTEX initialization
 Determine if initialization is required
 IF(JVXYZ.EQ.IVXYZ) GOTO 70
 Set indicators for types of input data and saving verticies
 JVXYZ = JVXYZ
 INDZ = 1; INDY = 1; INDX = 1; INDV = 1
 IF(JVXYZ.LT.1000) GOTO 30
 INDV = 2
 JVXYZ = JVXYZ - 1000
 IF(JVXYZ.LT.100) GOTO 40
 INDX = 2
 JVXYZ = JVXYZ - 100
 IF(JVXYZ.LT.10) GOTO 50
 INDY = 2
 JVXYZ = JVXYZ - 10
 IF(JVXYZ.LT.1) GOTO 60
 INDZ = 2
 JVXYZ = JVXYZ
 Rotation initialization
 Determine if initialization is required
 IF(PHI.EQ.SPHI.AND.THETA.EQ.STHETA) GOTO 80
 Compute rotation factors
 SPHI = SINF(0.0174532925*PHI)
 CPHI = COSF(0.0174532925*PHI)
 STHETA = SINF(0.0174532925*THETA)
 CTHETA = COSF(0.0174532925*THETA)
 A11 = CPHI
 A13 = -SPHI
 A21 = STHETA*SPHI
 A22 = -CTHETA
 A23 = STHETA*CPHI
 SPHI = PHI
 STHETA = THETA
 Processing procedures
 Set flag to move through the data arrays in the opposite direction
 INTL = -INCI
 Set indicator to the first point to be processed
 IF(I.LT.0) I = NPNTS + 1
 Loop to process each point in the data arrays
 DO 530 K=1,NPNTS
 Data calculations
 I = I + INCI
 GOTO (90, 100), INDX
 = YDATA(I) + (I-1)*SCALE

```

02240 100      X = XDATA(I)*XSCALE
02250 110      GOTO ( 120, 130 ), INDY
02260 120      X = YDATA(I) + (I-1)*YSCALE
02270      GOTO 140
02280 130      Y = YDATA(I)*YSCALE
02290 140      GOTO ( 150, 160 ), INDZ
02300 150      Z = ZDATA(I) + (NLINE-1)*ZSCALE
02310      GOTO 170
02320 160      Z = ZDATA(I)*ZSCALE
02330 C       data rotation
02340 170      XXX = A11*X + A13*Z + XREF
02350      XX = XXX
02360      IX = IFIX( XX*PIPI + 0.5 )
02370      YY = A21*X + A23*Z + YREF
02380      YY = YY + A22*X
02390      IY = IFIX( YY*PIPI + 0.5 )
02400 C       Restrict figure to plot page
02410      IF( IX.LE.0 ) IX = 1
02420      IF( IX.GT.LIMITX ) IX = LIMITX
02430      IF( IY.LT.10 ) IY = 10
02440      IF( IY.GT.NYPI ) IY = NYPI
02450      IF( K.NE.1 ) GOTO 250
02460 C       ( LOC ) is the position of the previous point with respect to
02470 the mask
02480 C       +1 above the mask
02490 C       0 within the limits of the mask
02500 C       -1 below the mask
02510 C       Procedure for initial point of each line
02520 C       Locate initial point with respect to the mask then
02530 C       update the mask
02540      LOW = IX + IX
02550      HIGH = LOW + 1
02560      MLLOW = MASK( LOW )
02570      MHIGH = MASK( HIGH )
02580      IF( MHIGH-IY ) 200, 210, 180
02590 180      IF( MLLOW-IY ) 190, 230, 220
02600 190      LOCOLD = 0
02610      GOTO 240
02620 200      MASK( HIGH ) = IY
02630      IF( MLLOW.EQ.-1 ) MASK( LOW ) = IY
02640 210      LOCOLD = 1
02650      GOTO 240
02660 220      MASK( LOW ) = IY
02670 230      LOCOLD = -1
02680 C       move the raised pen to the initial point
02690 240      CALL IPLOT( IX, IY, 3 )
02700      JX = IX; IY = IY; IYREF = IY
02710 C       store vertices if requested
02720      IF( INOV.EQ.-1 ) GOTO 530
02730      INDEX = INCI + 6
02740      VERTEX( INDEX ) = XX
02750      VERTEX( INDEX+1 ) = YY
02760      VERTEX( INDEX+8 ) = XXX
02770      VERTEX( INDEX+9 ) = YYY
02780      IF( NLINE.NE.1 ) GOTO 530
02790      VERTEX( 1 ) = XX
02800      VERTEX( 2 ) = YY
02810      VERTEX( 9 ) = XXX
02820      VERTEX( 10 ) = YYY
02830      GOTO 530
02840 C       Special case where change in X co-ordinate is zero
02850 C       A special provision is made at this point so that a line
02860 will not mask itself as long as the X coordinate remains
02870 constant
02880 250      IF( IX.NE.JX ) GOTO 260
02890      JY = IY
02900      GOTO 280
02910 C       compute constants for linear interpolation
02920 260      YINC = FUDAT(IY-JY)/ABS( FUDAT(IX-JX) )
02930      INCX = (IX-JX)/IABS(IX-JX)
02940      YJ = JY
02950 C       Perform linear interpolation at each incremental step on
02960 the X-axis
02970 270      JX = JX + INCX
02980      YJ = YJ + YINC
02990      JY = IFIX( YJ + 0.5 )
03000 C       Locate the current point with respect to the mask at that
03010 point then plot the increment as a function of the
03020 location of the previous point with respect to its mask
03030      LOW = JX + JX
03040      HIGH = LOW - 1
03050      MLLOW = MASK( LOW )
03060      MHIGH = MASK( HIGH )
03070 280      IF( MHIGH-JY ) 300, 340, 290
03080 290      IF( MLLOW-JY ) 310, 320, 320
03090 C       The current point is above the mask
03100 300      LOC = +1

```

03140 310 IF(EUCCESS POINT IS WITHIN THE MASK
 03130 310 LOC = 0
 03140 310 IF(LOC>0) 340, 350, 330
 03150 C The current point is below the mask
 03160 320 LOC = -1
 03170 320 IF(LOC<0) 510, 450, 440
 03180 C Plot from above the mask to within the mask
 03190 330 IF(MHIGH.LE.IYREF) CALL IPLOT(JX, MHIGH, 2)
 03200 330 GOTO 350
 03210 C Plot from below the mask to within the mask.
 03220 340 IF(MLOW.GE.IYREF) CALL IPLOT(JX, MLOW, 2)
 03230 C Plot from within the mask to within the mask
 03240 350 CALL IPLOT(JX, JY, 3)
 03250 350 GOTO 520
 03260 C Plot from below the mask to above the mask
 03270 360 IF(MLOW>IYREF) 370, 380, 380
 03280 C Plot from within the mask to above the mask
 03290 370 IF(MHIGH>IYREF) 400, 390, 390
 03300 380 CALL IPLOT(JX, MLOW, 2)
 03310 390 CALL IPLOT(JX, MHIGH, 3)
 03320 390 GOTO 430
 03330 400 IF(MHIGH.EQ.-1) GOTO 430
 03340 400 OLDHI = HIGH - 2*INCX
 03350 410 IF(MASK(OLDHI)-JY) 420, 420, 410
 03360 410 CALL IPLOT(JX, JY, 3)
 03370 410 GOTO 430
 03380 420 CALL IPLOT(JX-INCX, MASK(OLDHI), 3)
 03390 C Plot from above the mask to above the mask
 03400 430 MASK(HIGH) = JY
 03410 430 IF(MLOW.EQ.-1) MASK(LOW) = JY
 03420 430 CALL IPLOT(JX, JY, 2)
 03430 430 GOTO 520
 03440 C PLOT FROM ABOVE THE MASK TO BELOW THE MASK.
 03450 440 IF(MHIGH-IYREF) 460, 460, 450
 03460 C Plot from within the mask to below the mask
 03470 450 IF(MLOW-IYREF) 470, 470, 480
 03480 460 CALL IPLOT(JX, MHIGH, 2)
 03490 470 CALL IPLOT(JX, MLOW, 3)
 03500 470 GOTO 510
 03510 480 OLDLOW = LOW - 2*INCX
 03520 480 IF(MASK(OLDLOW)-JY) 490, 500, 500
 03530 490 CALL IPLOT(JX, JY, 3)
 03540 490 GOTO 510
 03550 500 CALL IPLOT(JX-INCX, MASK(OLDLOW), 3)
 03560 C Plot from below the mask to below the mask
 03570 510 MASK(LOW) = JY
 03580 510 CALL IPLOT(JX, JY, 2)
 03590 520 IYREF = JY
 03600 520 LOCOLD = LOC
 03610 520 IF(JX.GE.IX) GOTO 270
 03620 530 CONTINUE
 03630 C Raise pen
 03640 530 CALL IPLOT(JX, JY, 3)
 03650 C Store vertices if requested
 03660 530 IF(INOV.EQ.1) GOTO 540
 03670 530 INDEX = -INCI + 6
 03680 530 VERTEX(INDEX) = XX
 03690 530 VERTEX(INDEX+1) = YY
 03700 530 VERTEX(INDEX+8) = XXX
 03710 530 VERTEX(INDEX+9) = YYY
 03720 530 IF(NLINE.NE.1) GOTO 540
 03730 530 VERTEX(3) = XX
 03740 530 VERTEX(4) = YY
 03750 530 VERTEX(11) = XXX
 03760 530 VERTEX(12) = YYY
 03770 540 I = I - 1
 03780 C Return to calling program
 03790 RETURN
 03800 C Option to modify the masking technique to be used on the
 03810 C following figure so as to plot only above all previous
 03820 C lines.
 03830 550 INIT = 0
 03840 RETURN
 03850 END
 03860 C
 03870 C SUBROUTINE FRAMES(INCOR, VERTEX, MASK)
 03880 C Routine to plot a frame on the projection of a
 03890 C 3-dimensional figure as drawn by PLOT3D.
 03900 C Input parameters -
 03910 C INCOR - number of the vertex of the figure which
 03920 C appears to be furthest in the background
 03930 C (minus Z direction).
 03940 C VERTEX - array containing the coordinates of the
 03950 C vertices of this figure as returned from
 03960 C PLOT3D on the last call.
 03970 C MASK - array containing the mask for this figure
 03980 C as returned by PLD130 on the last call.
 03990 C

```

04010      C      order as their coordinates appear in VERTEX.
04020      CC     The MASK array is altered by this routine,
04030      C      but the plotter origin is not moved.
04040      DIMENSION VERTEX(1), MASK(1), ARRAY(14)
04050      I = 2*IHOR
04060      IF( I.GT.2 ) I = 2
04070      IF( I.GT.8 ) I = 8
04080      C      The vertices which may be hidden
04090      C      are drawn by a call to PLOT3D.
04100      ARRAY(1) = VERTEX(I-1)
04110      ARRAY(8) = VERTEX(I)
04120      ARRAY(2) = VERTEX(I+7)
04130      ARRAY(9) = VERTEX(I+8)
04140      ARRAY(4) = ARRAY(2)
04150      ARRAY(11) = ARRAY(9)
04160      ARRAY(6) = ARRAY(2)
04170      ARRAY(13) = ARRAY(9)
04180      ARRAY(7) = ARRAY(1)
04190      ARRAY(14) = ARRAY(8)
04200      I = I - 2
04210      IF( I.EQ.0 ) I = 8
04220      ARRAY(3) = VERTEX(I+7)
04230      ARRAY(10) = VERTEX(I+8)
04240      I = I + 4
04250      IF( I.GT.8 ) I = I - 8
04260      ARRAY(5) = VERTEX(I+7)
04270      ARRAY(12) = VERTEX(I+8)
04280      CALL PLOT3D( 110, ARRAY, ARRAY(8), 0.0, 1.0, 1.0, 0.0,
04290      1, 2, 7, 0.0, 0.0, 0.0, 0.0, 0.0, MASK, 0 )
04300      C      The remaining vertices are drawn by calls to PLOT.
04310      CALL PLOT( VERTEX(I-1), VERTEX(I), 3 )
04320      I = I - 2
04330      DO 10 J=1,3
04340      I = I+2
04350      IF( I.EQ.10 ) I = 2
04360      CALL PLOT( VERTEX(I+7), VERTEX(I+8), 2 )
04370      10    CONTINUE
04380      CALL PLOT( VERTEX(I-1), VERTEX(I), 2 )
04390      I = I - 2
04400      IF( I.EQ.0 ) I = 8
04410      CALL PLOT( VERTEX(I-1), VERTEX(I), 3 )
04420      CALL PLOT( VERTEX(I+7), VERTEX(I+8), 2 )
04430      RETURN
04440      END

```

```

000100      SUBROUTINE PLDIF(X, Y, IVIS)
000200      IVIS = 1
000300      IVIS = 0
000400      RETURN
000500      END
000600
000700
000800
000900      SUBROUTINE PLDT(X, Y, Z)
000910      D1 = EXP(-X)
000920      D2 = EXP(-Y)
000930      D3 = EXP(-Z)
001000      D4 = EXP(-X-Y-Z)
001100      D5 = EXP(-X-Z)
001200      D6 = EXP(-Y-Z)
001300      D7 = EXP(-X-Y)
001400      D8 = EXP(-X)
001500      D9 = EXP(-Y)
001600      D10 = EXP(-Z)
001700      D11 = EXP(-X-Y-Z)
001800      D12 = EXP(-X-Z)
001900      D13 = EXP(-Y-Z)
002000      D14 = EXP(-X-Y)
002100      D15 = EXP(-X)
002200      D16 = EXP(-Y)
002300      D17 = EXP(-Z)
002400      D18 = EXP(-X-Y-Z)
002500      D19 = EXP(-X-Z)
002600      D20 = EXP(-Y-Z)
002700      D21 = EXP(-X-Y)
002800      D22 = EXP(-X)
002900      D23 = EXP(-Y)
003000      D24 = EXP(-Z)
003100      D25 = EXP(-X-Y-Z)
003200      D26 = EXP(-X-Z)
003300      D27 = EXP(-Y-Z)
003400      D28 = EXP(-X-Y)
003500      D29 = EXP(-X)
003600      D30 = EXP(-Y)
003700      D31 = EXP(-Z)
003800      D32 = EXP(-X-Y-Z)
003900      D33 = EXP(-X-Z)
004000      D34 = EXP(-Y-Z)
004100      D35 = EXP(-X-Y)
004200      D36 = EXP(-X)
004300      D37 = EXP(-Y)
004400      D38 = EXP(-Z)
004500      D39 = EXP(-X-Y-Z)
004600      D40 = EXP(-X-Z)
004700      D41 = EXP(-Y-Z)
004800      D42 = EXP(-X-Y)
004900      D43 = EXP(-X)
005000      D44 = EXP(-Y)
005100      D45 = EXP(-Z)
005200      D46 = EXP(-X-Y-Z)
005300      D47 = EXP(-X-Z)
005400      D48 = EXP(-Y-Z)
005500      D49 = EXP(-X-Y)
005600      D50 = EXP(-X)
005700      D51 = EXP(-Y)
005800      D52 = EXP(-Z)
005900      D53 = EXP(-X-Y-Z)
006000      D54 = EXP(-X-Z)
006100      D55 = EXP(-Y-Z)
006200      D56 = EXP(-X-Y)
006300      D57 = EXP(-X)
006400      D58 = EXP(-Y)
006500      D59 = EXP(-Z)
006600      D60 = EXP(-X-Y-Z)
006700      D61 = EXP(-X-Z)
006800      D62 = EXP(-Y-Z)
006900      D63 = EXP(-X-Y)
007000      D64 = EXP(-X)
007100      D65 = EXP(-Y)
007200      D66 = EXP(-Z)
007300      D67 = EXP(-X-Y-Z)
007400      D68 = EXP(-X-Z)
007500      D69 = EXP(-Y-Z)
007600      D70 = EXP(-X-Y)
007700      D71 = EXP(-X)
007800      D72 = EXP(-Y)
007900      D73 = EXP(-Z)
008000      D74 = EXP(-X-Y-Z)
008100      D75 = EXP(-X-Z)
008200      D76 = EXP(-Y-Z)
008300      D77 = EXP(-X-Y)
008400      D78 = EXP(-X)
008500      D79 = EXP(-Y)
008600      D80 = EXP(-Z)
008700      D81 = EXP(-X-Y-Z)
008800      D82 = EXP(-X-Z)
008900      D83 = EXP(-Y-Z)
009000      D84 = EXP(-X-Y)
009100      D85 = EXP(-X)
009200      D86 = EXP(-Y)
009300      D87 = EXP(-Z)
009400      D88 = EXP(-X-Y-Z)
009500      D89 = EXP(-X-Z)
009600      D90 = EXP(-Y-Z)
009700      D91 = EXP(-X-Y)
009800      D92 = EXP(-X)
009900      D93 = EXP(-Y)
010000      D94 = EXP(-Z)
010100      D95 = EXP(-X-Y-Z)
010200      D96 = EXP(-X-Z)
010300      D97 = EXP(-Y-Z)
010400      D98 = EXP(-X-Y)
010500      D99 = EXP(-X)
010600      D100 = EXP(-Y)
010700      D101 = EXP(-Z)
010800      D102 = EXP(-X-Y-Z)
010900      D103 = EXP(-X-Z)
011000      D104 = EXP(-Y-Z)
011100      D105 = EXP(-X-Y)
011200      D106 = EXP(-X)
011300      D107 = EXP(-Y)
011400      D108 = EXP(-Z)
011500      D109 = EXP(-X-Y-Z)
011600      D110 = EXP(-X-Z)
011700      D111 = EXP(-Y-Z)
011800      D112 = EXP(-X-Y)
011900      D113 = EXP(-X)
012000      D114 = EXP(-Y)
012100      D115 = EXP(-Z)
012200      D116 = EXP(-X-Y-Z)
012300      D117 = EXP(-X-Z)
012400      D118 = EXP(-Y-Z)
012500      D119 = EXP(-X-Y)
012600      D120 = EXP(-X)
012700      D121 = EXP(-Y)
012800      D122 = EXP(-Z)
012900      D123 = EXP(-X-Y-Z)
013000      D124 = EXP(-X-Z)
013100      D125 = EXP(-Y-Z)
013200      D126 = EXP(-X-Y)
013300      D127 = EXP(-X)
013400      D128 = EXP(-Y)
013500      D129 = EXP(-Z)
013600      D130 = EXP(-X-Y-Z)
013700      D131 = EXP(-X-Z)
013800      D132 = EXP(-Y-Z)
013900      D133 = EXP(-X-Y)
014000      D134 = EXP(-X)
014100      D135 = EXP(-Y)
014200      D136 = EXP(-Z)
014300      D137 = EXP(-X-Y-Z)
014400      D138 = EXP(-X-Z)
014500      D139 = EXP(-Y-Z)
014600      D140 = EXP(-X-Y)
014700      D141 = EXP(-X)
014800      D142 = EXP(-Y)
014900      D143 = EXP(-Z)
015000      D144 = EXP(-X-Y-Z)
015100      D145 = EXP(-X-Z)
015200      D146 = EXP(-Y-Z)
015300      D147 = EXP(-X-Y)
015400      D148 = EXP(-X)
015500      D149 = EXP(-Y)
015600      D150 = EXP(-Z)
015700      D151 = EXP(-X-Y-Z)
015800      D152 = EXP(-X-Z)
015900      D153 = EXP(-Y-Z)
016000      D154 = EXP(-X-Y)
016100      D155 = EXP(-X)
016200      D156 = EXP(-Y)
016300      D157 = EXP(-Z)
016400      D158 = EXP(-X-Y-Z)
016500      D159 = EXP(-X-Z)
016600      D160 = EXP(-Y-Z)
016700      D161 = EXP(-X-Y)
016800      D162 = EXP(-X)
016900      D163 = EXP(-Y)
017000      D164 = EXP(-Z)
017100      D165 = EXP(-X-Y-Z)
017200      D166 = EXP(-X-Z)
017300      D167 = EXP(-Y-Z)
017400      D168 = EXP(-X-Y)
017500      D169 = EXP(-X)
017600      D170 = EXP(-Y)
017700      D171 = EXP(-Z)
017800      D172 = EXP(-X-Y-Z)
017900      D173 = EXP(-X-Z)
018000      D174 = EXP(-Y-Z)
018100      D175 = EXP(-X-Y)
018200      D176 = EXP(-X)
018300      D177 = EXP(-Y)
018400      D178 = EXP(-Z)
018500      D179 = EXP(-X-Y-Z)
018600      D180 = EXP(-X-Z)
018700      D181 = EXP(-Y-Z)
018800      D182 = EXP(-X-Y)
018900      D183 = EXP(-X)
019000      D184 = EXP(-Y)
019100      D185 = EXP(-Z)
019200      D186 = EXP(-X-Y-Z)
019300      D187 = EXP(-X-Z)
019400      D188 = EXP(-Y-Z)
019500      D189 = EXP(-X-Y)
019600      D190 = EXP(-X)
019700      D191 = EXP(-Y)
019800      D192 = EXP(-Z)
019900      D193 = EXP(-X-Y-Z)
020000      D194 = EXP(-X-Z)
020100      D195 = EXP(-Y-Z)
020200      D196 = EXP(-X-Y)
020300      D197 = EXP(-X)
020400      D198 = EXP(-Y)
020500      D199 = EXP(-Z)
020600      D200 = EXP(-X-Y-Z)
020700      D201 = EXP(-X-Z)
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020900      D203 = EXP(-X-Y)
021000      D204 = EXP(-X)
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021200      D206 = EXP(-Z)
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021600      D210 = EXP(-X-Y)
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021900      D213 = EXP(-Z)
022000      D214 = EXP(-X-Y-Z)
022100      D215 = EXP(-X-Z)
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022400      D218 = EXP(-X)
022500      D219 = EXP(-Y)
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022700      D221 = EXP(-X-Y-Z)
022800      D222 = EXP(-X-Z)
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023100      D225 = EXP(-X)
023200      D226 = EXP(-Y)
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023400      D228 = EXP(-X-Y-Z)
023500      D229 = EXP(-X-Z)
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023700      D231 = EXP(-X-Y)
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024200      D236 = EXP(-X-Z)
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024400      D238 = EXP(-X-Y)
024500      D239 = EXP(-X)
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024900      D243 = EXP(-X-Z)
025000      D244 = EXP(-Y-Z)
025100      D245 = EXP(-X-Y)
025200      D246 = EXP(-X)
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035900      D353 = EXP(-Z)
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049400      D488 = EXP(-X-Z)
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058200      D576 = EXP(-Y)
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063200      D626 = EXP(-Z)
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063900      D633 = EXP(-Z)
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069500      D689 = EXP(-Z)
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069900      D693 = EXP(-X-Y)
070000      D694 = EXP(-X)
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072400      D718 = EXP(-X-Y-Z)
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072900      D723 = EXP(-Y)
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073700      D731 = EXP(-Z)
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073900      D733 = EXP(-X-Z)
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074100      D735 = EXP(-X-Y)
074200      D736 = EXP(-X)
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074500      D739 = EXP(-X-Y-Z)
074600      D74
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09203
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09403
09503
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10303
10403
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10603
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11103
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11403
11503
11603

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      INTEGER TTY
      INTEGER X(256),BLANK,DDT
      DATA A1/R1,256.,0.,256./,V/0.10,0.55,0.40,0.55/,TTY/1/
      DATA BLANK,DDT/1H,1B./
      CALL VIIDEV(TTY)
      READ LDEN
      READ NINONIN(100)
      READ VPORCV(100)
      DO 100 I=1,256
      READ(X(I)),(X(J),J=1,256)
      DO 100 J=1,256
      READ(X(J)).EQ.100D TO 100
      Y1=1
      Y1=Y1
      READ DTNE(X1,Y1,0)
      READ DTNE(X1,Y1,1)
      READ DTNE(X1,Y1,2)
      STOP
      E40
```

00100 THIS PROGRAM IS FOR FIXED THRESHOLD
00200 TECHNIQUE. IT READS THE DATA OF THE
00300 GIVEN PICTURE AND COMPARES IT WITH A
00400 FIXED THRESHOLD OF 16.
00500 DIMENSION V(4),W1(4)
00600 INTEGER TTY
00700 INTEGER XC(128,128),YC(128,128)
00800 DATA X1/D.,128.,0.,128./,V/0.50,0.80,0.50,0.80/,TTY/1/
00900 CALL NIDEV(TTY)
01000 SCALD IDEM
01100 SCADD WINDOW(W1(1))
01200 SCALL VPJRT(V(1))
01300 READ*, ((X(I,J),J=1,128),I=1,128)
01400 DO 10 I=1,128
01500 DO 10 J=1,128
01600 IF(X(I,J).GT.16)GO TO 10
01700 X1=I
01800 Y1=J
01900 SCALL LINE(X1,Y1,0)
02000 SCALL LINE(X1,Y1,1)
02100 10 CONTINUE
02200 ACCEPT*,OK
02300 STOP
02400 EVO

```
00001  
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00005      C PROGRAM FOR THE GENERATION OF  
00006          256*256 PICTURE OF  
00053          LINCOLN BY ORDERED DITHER  
00100          DIMENSION V(4),W1(4)  
00200          INTEGER TTY  
00300          INTEGER X(256),Y(256),BLANK, DOT  
00400      C OPEN(UNIT=22,DEVICE=DSKD,FILE='FOR22.DAT')  
00500      C OPEN(UNIT=23,DEVICE=DSKD,FILE='FOR23.DAT')  
00600          DATA W1/0.,256.,0.,256./,V/0.,0.25,0.,0.25/,TTY/1/  
00700          DATA BLANK, DOT/1H ,1H./  
00800          CALL NITDEV(TTY)  
00900          CALL IDEN  
01000          CALL WINDW(W1(1))  
01100          CALL VPDRT(V(1))  
01200          DO 100 I=1,256  
01300          READ(24,*),(X(J),J=1,256)  
01400          READ(23,*),(Y(J),J=1,256)  
01500          DO 100 J=1,256  
01600          IF(X(J).GT.Y(J))GO TO 100  
01700          X1=I  
01800          Y1=J  
01900          CALL LINE(X1,Y1,0)  
02000          CALL LINE(X1,Y1,1)  
02100          CONTINUE  
02200      C 100 PRINT 110  
02300      C 110 FORMAT(//20X,'THE BILEVEL PICTURE IS'/30X,'-----')  
02400      C 120 PRINT120,((Z(I,J),J=1,64),I=1,64)  
02500          FORMAT(5X,64A1)  
02600          ACCEPT*,OK  
02700          STOP  
02800          END
```

```

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C      PROGRAM CONAVE.FOR
C      THIS PROGRAM GENERATES A BILEVEL
C      PICTURE BY THE CONSTRAINED AVERAGE
C      METHOD. THE OUTPUT PICTURE IS A
C      64*64 BILEVEL PICTURE
C      PRINTED ON THE LINE PRINTER.
C      INTEGER I,J,X(64,64),Y(64,64),Z(64,64),BLANK,DOT
C      DATA BLANK, DOT /1H, 1H/
C      READ*,CX(I,J),I=1,64,J=1,64
C      PRINTING OF THE MULTILEVEL PICTURE DATA.
C      PRINT 10
C      10 FORMAT//80X,'THE PICTURE MATRIX IS',/80X,'-----'
C      DO 20 I=1,64
C      20 PRINT 30,(X(I,J),J=1,64)
C      30 FORMAT//64T2
C      ACCUMULATING THE AVERAGE INTENSITY BY TAKING EXPLICIT SUM
C      OVER THE IMMEDIATE NEIGHBORHOOD.
C      DO 40 J=1,64
C      40 IC1,J,J,X(1,J)
C      CONTINUE
C      DO 50 I=2,63
C      50 IC2,J,I,X(I,1)
C      DO 60 J=2,63
C      60 IC3,I,J,X(I-1,J-1)+X(I-1,J)+X(I-1,J+1)
C      IC3=IC3+X(I,J)+X(I,J+1)+X(I+1,J-1)+X(I+1,J)
C      IC3=IC3/6+0.5
C      CONTINUE
C      60 X(I,64)=X(I,64)
C      CONTINUE
C      70 J=1,64
C      NC64,J,X(64,J)
C      CONTINUE
C      PRINTING OF THE THRESHOLD MATRIX
C      DO 300 I=1,64
C      300 DO 320 J=1,64
C      320 Y(I,J)=C2.+(C1.-4./31.0*X(I,J)))
C      CONTINUE
C      300 PRINT 310
C      310 FORMAT//80X,'THE THRESHOLD MATRIX IS',/80X,'-----'
C      DO 320 I=1,64
C      320 PRINT 330,(N(I,J),J=1,64)
C      330 FORMAT//64T2
C      SEPARATION OF INTENSITIES WITH MODIFIED THRESHOLDS AND
C      FORMING OF THE BILEVEL PICTURE
C      DO 400 I=1,64
C      400 DO 390 J=1,64
C      IF(X(I,J).LE.Y(I,J))GO TO 380
C      CONTINUE
C      380 Z(I,J)=BLANK
C      390 IF 390 Z(I,J)=DOT
C      CONTINUE
C      PRINTING OF THE BILEVEL PICTURE
C      PRINT 410
C      410 FORMAT//80X,'THE BILEVEL PICTURE IS',/80X,'-----'
C      PRINT 420,(Z(I,J),J=1,64),I=1,64)
C      FORMAT(5X,54A1)
C      STOP
C      END

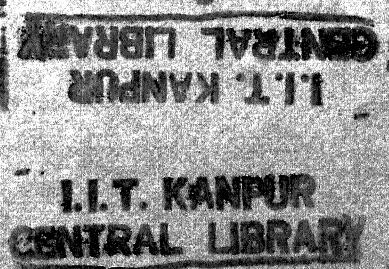
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00002 C
00100 PICTURE BY ERROR DIFFUSION TECHNIQUE
00200 DIMENSION V(A),W(10)
00300 INTEGER PTY
00400 INTEGER X(128,128),Y(128,128),E(128,128),Z(128,128),BLANK,DDT
00500 DATA #1/0,128,0,128,/,#0.25,0.55,0.25,0.55/,PTY/1/
00600 DATA BLANK,DDT/1H,1H./
00700 CALL INITDEV(PTY)
00800 READ IDEM
00900 READ WINOW(W(11))
01000 CALL VPDRIVC(1)
01100 READ*, ((X(I,J),J=1,128),I=1,128)
01200 DO 30 J=1,128
01300 E(1,J)=0
01400 Y(1,J)=X(1,J)
01500 IF(Y(1,J).GT.15)GO TO 40
01600 XI=1
01700 YI=J
01800 CALL LINE(XI,YI,0)
01900 CALL LINE(XI,YI,1)
02000 CONTINUE
02100 DO 40 J=1,128
02200 EC(2,J)=0
02300 Y(2,J)=X(2,J)
02400 IF(Y(2,J).GT.15)GO TO 40
02500 XI=1
02600 YI=J
02700 CALL LINE(XI,YI,0)
02800 CALL LINE(XI,YI,1)
02900 CONTINUE
03000 DO 50 J=3,128
03100 Y(1,J)=X(1,J)
03200 EC(1,J)=0
03300 IF(Y(1,J).GT.15)GO TO 41
03400 XI=1
03500 YI=J
03600 CALL LINE(XI,YI,0)
03700 CALL LINE(XI,YI,1)
03800 CONTINUE
03900 DO 60 J=3,128
04000 Y(1,J)=X(1,J)+0.15*E(1,J+1)+0.1*E(1,J-2)+0.06*E(1-1,J+2)
04100 E(0,J)=E(1,J-1,J+1)+0.15*E(1-1,J)+0.1*E(1,J-1,J+1)+0.06*E(1-1,J-2)
04200 E(1,J)=0.03*E(1-2,J+2)+0.06*E(1-2,J+1)+0.1*E(1-2,J)+0.06*E(1-2,J-1)
04300 E(2,J)=0.03*E(1-2,J-2)+0.06*E(1-2,J-1)+0.1*E(1-2,J)+0.06*E(1-2,J-1)
04400 IF(Y(1,J).GT.15)GO TO 62
04500 EC(1,J)=Y(1,J)
04600 XI=1
04700 YI=J
04800 CALL LINE(XI,YI,0)
04900 CALL LINE(XI,YI,1)
05000 CONTINUE
05100 DO 62 J=3,128
05200 Y(1,J)=X(1,J)+0.15*E(1,J+1)+0.1*E(1,J-2)+0.06*E(1-1,J+2)
05300 E(0,J)=E(1,J-1,J+1)+0.15*E(1-1,J)+0.1*E(1,J-1,J+1)+0.06*E(1-1,J-2)
05400 E(1,J)=0.03*E(1-2,J+2)+0.06*E(1-2,J+1)+0.1*E(1-2,J)+0.06*E(1-2,J-1)
05500 E(2,J)=0.03*E(1-2,J-2)+0.06*E(1-2,J-1)+0.1*E(1-2,J)+0.06*E(1-2,J-1)
05600 IF(Y(1,J).GT.15)GO TO 62
05700 EC(1,J)=Y(1,J)
05800 XI=1
05900 YI=J
06000 CALL LINE(XI,YI,0)
06100 CALL LINE(XI,YI,1)
06200 CONTINUE
06300 DO 63 J=1,127
06400 Y(1,J)=X(1,J)
06500 EC(1,J)=0
06600 IF(Y(1,J).GT.15)GO TO 63
06700 XI=1
06800 YI=J
06900 CALL LINE(XI,YI,0)
07000 CALL LINE(XI,YI,1)
07100 CONTINUE
07200 DO 65 J=1,128
07300 Y(1,J)=X(1,J)
07400 EC(1,J)=0
07500 IF(Y(1,J).GT.15)GO TO 65
07600 XI=1
07700 YI=J
07800 CALL LINE(XI,YI,0)
07900 CALL LINE(XI,YI,1)
08000 CONTINUE
08100 ACCEPT,OK
08200 STOP
08300 END

```



Acc. No. A

THE PRIVATE PROPERTY IN

2.637395 , 2.307395

2-007895 THE SINGER READING TEST

I.I.T. KANPUR
CENTRAL LIBRARY

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THE INPUT PATTERN IS

2.397895 , 2.397895 , 2.397895 , 2.397895 , 0.6931472 , 2.397895 , 2.397895
2.397895

THE SYSTEM RESPONSE IS

4.29	2.13	4.29	6.48	6.58	6.68	6.78	6.88	6.98	7.08	7.19	7.29	7.33	7.49	7.19	7.08	6.98	6.88	6.78
2.13	4.29	7.13	11.52	11.69	11.87	12.05	12.23	12.41	12.59	12.78	12.97	13.02	12.97	12.78	12.59	12.41	12.23	12.05
7.13	4.29	6.48	11.52	18.18	18.45	18.72	19.00	19.28	19.57	19.86	20.16	20.46	20.54	20.46	20.16	19.86	19.57	19.28
4.29	11.52	6.48	11.69	18.45	18.72	19.00	19.28	19.57	19.86	20.16	20.46	20.76	20.81	20.76	20.16	20.16	19.86	19.57
11.52	6.48	6.58	11.69	18.45	18.72	19.00	19.28	19.57	19.86	20.16	20.46	20.76	20.81	20.76	20.16	20.16	19.86	19.57
11.69	6.48	6.58	11.87	18.72	19.00	19.28	19.57	19.86	20.16	20.46	20.76	21.07	21.15	21.17	21.16	20.46	20.16	19.86
11.87	6.48	6.78	12.05	19.00	19.28	19.57	19.86	20.16	20.46	20.76	21.07	21.38	21.47	21.38	21.07	20.76	20.46	20.16
12.05	6.78	6.88	12.23	19.28	19.57	19.86	20.16	20.46	20.76	21.07	21.38	21.70	21.78	21.70	21.38	21.07	20.76	20.46
12.23	6.88	6.98	12.41	19.57	19.86	20.16	20.46	20.76	21.07	21.38	21.70	22.02	22.11	22.02	21.70	21.38	21.07	20.76
12.41	6.98	7.08	12.59	19.86	20.16	20.46	20.76	21.07	21.38	21.70	22.02	22.34	22.43	22.34	22.02	21.70	21.38	21.07
12.59	7.08	7.19	12.78	20.16	20.46	20.76	21.07	21.38	21.70	22.02	22.34	22.67	22.76	22.67	22.34	22.02	21.70	21.38
12.78	7.19	7.29	12.97	20.46	20.76	21.07	21.38	21.70	22.02	22.34	22.67	23.01	23.10	23.01	22.67	22.34	22.02	21.70
12.97	7.29	7.33	13.02	20.54	20.84	21.15	21.47	21.78	22.11	22.43	22.75	23.10	23.19	23.10	22.76	22.43	22.11	21.78
13.02	7.33	7.29	12.97	20.46	20.76	21.07	21.38	21.70	22.02	22.34	22.67	23.01	23.10	23.01	22.67	22.34	22.02	21.70
12.97	7.29	7.19	12.78	20.16	20.46	20.76	21.07	21.38	21.70	22.02	22.34	22.67	22.76	22.67	22.34	22.02	21.70	21.38
12.78	7.19	7.08	12.59	19.86	20.16	20.46	20.76	21.07	21.38	21.70	22.02	22.34	22.43	22.34	22.02	21.70	21.38	21.07
12.59	7.08	6.98	12.41	19.57	19.86	20.16	20.46	20.76	21.07	21.38	21.70	22.02	22.11	22.02	21.70	21.38	21.07	20.76
12.41	6.98	6.88	12.23	19.28	19.57	19.86	20.16	20.46	20.76	21.07	21.38	21.70	21.78	21.70	21.38	21.07	20.76	20.46
12.23	6.88	6.78	12.05	19.00	19.28	19.57	19.86	20.16	20.46	20.76	21.07	21.38	21.47	21.38	21.07	20.76	20.46	20.16
12.05	6.78	6.69	11.87	18.72	19.00	19.28	19.57	19.86	20.16	20.46	20.76	21.07	21.15	21.07	20.76	20.46	20.16	19.86
11.87	6.69	6.58	11.69	18.45	18.72	19.00	19.28	19.57	19.86	20.16	20.46	20.76	21.07	21.15	21.07	20.76	20.46	19.86
11.69	6.58	6.48	11.52	18.18	18.45	18.72	19.00	19.28	19.57	19.86	20.16	20.46	20.54	20.46	20.16	19.86	19.57	19.28
11.52	6.48	6.48	7.13	14.52	11.69	11.87	12.05	12.23	12.41	12.59	12.78	12.97	13.02	12.97	12.78	12.59	12.41	12.23
7.13	4.29	4.29	2.13	4.29	6.48	6.58	6.68	6.78	6.88	6.98	7.08	7.19	7.29	7.33	7.29	7.19	7.08	6.98

THE SYSTEM RESPONSE IS		THE SYSTEM RESPONSE IS																	
2.13	4.29	6.48	8.58	6.58	6.78	6.83	6.98	7.08	7.19	7.29	7.33	7.37	7.47	7.08	6.98	6.88	6.73	6.6	
2.13	7.13	10.01	10.15	10.31	10.46	10.52	10.78	10.93	11.10	11.27	11.09	11.21	11.05	10.89	10.73	10.67	10.42	10.0	
2.78	6.48	11.62	15.54	16.89	17.14	17.40	17.65	17.92	18.18	18.45	18.73	18.76	18.03	18.41	18.03	17.87	17.61	17.05	17.
4.95	6.58	11.69	15.89	17.11	17.40	17.65	17.92	18.18	18.45	18.73	19.01	19.06	18.49	18.03	18.40	18.13	17.87	17.61	17.
5.02	6.68	11.87	17.14	17.40	17.65	17.92	18.18	18.45	18.73	19.01	19.29	19.35	18.47	18.05	18.08	18.40	18.13	17.87	17.
5.09	6.78	12.05	17.40	17.65	17.92	18.18	18.42	18.73	19.01	19.29	19.57	19.63	19.02	19.23	18.95	18.68	18.40	18.13	17.
5.17	6.88	12.23	17.55	17.92	18.18	18.45	18.73	19.01	19.29	19.57	19.85	19.92	19.31	19.52	19.23	18.95	18.68	18.40	18.
5.25	6.98	12.41	17.92	18.13	18.45	18.73	19.01	19.29	19.57	19.85	20.15	20.22	20.20	19.31	19.52	19.23	18.95	18.68	18.
5.32	7.08	12.59	18.18	18.45	18.73	19.01	19.29	19.57	19.86	20.15	20.45	20.52	20.20	19.31	19.52	19.23	18.95	18.68	18.
5.40	7.19	12.78	18.45	18.73	19.01	19.29	19.57	19.86	20.16	20.45	20.75	20.82	20.14	20.40	20.10	19.81	19.52	19.23	18.
5.48	7.29	12.97	18.73	19.01	19.29	19.57	19.85	20.15	20.46	20.76	21.06	21.13	21.21	21.70	20.40	20.10	19.81	19.52	19.
5.57	7.33	13.02	18.78	19.05	19.35	19.53	19.92	20.22	20.52	20.82	21.13	21.19	21.37	21.75	20.45	20.16	19.87	19.58	19.
5.58	7.29	12.97	18.73	19.01	19.29	19.57	19.87	20.15	20.46	20.75	21.06	21.13	21.21	21.70	20.40	20.10	19.81	19.52	19.
5.57	7.19	12.78	18.45	18.73	19.01	19.29	19.57	19.86	20.16	20.45	20.75	20.82	20.14	20.40	20.10	19.81	19.52	19.23	18.
5.48	7.08	12.59	18.18	18.45	18.73	19.01	19.29	19.57	19.86	20.15	20.45	20.52	20.20	20.40	19.81	19.52	19.23	18.95	18.
5.40	6.98	12.41	17.92	18.13	18.45	18.73	19.01	19.29	19.57	19.85	20.15	20.22	20.14	19.31	19.52	19.23	18.95	18.68	18.
5.32	6.88	12.23	17.55	17.92	18.18	18.45	18.73	19.01	19.29	19.57	19.86	19.92	19.31	19.52	19.23	18.95	18.68	18.40	18.
5.25	6.78	12.05	17.40	17.65	17.92	18.18	18.42	18.73	19.01	19.29	19.57	19.63	19.52	19.21	18.95	18.68	18.40	18.13	17.
5.17	6.68	11.87	17.14	17.40	17.55	17.92	18.18	18.45	18.73	19.01	19.29	19.35	19.23	18.95	18.68	18.40	18.13	17.87	17.
5.09	6.58	11.69	15.89	17.14	17.40	17.65	17.92	18.18	18.45	18.73	19.01	19.06	18.45	18.03	18.40	18.13	17.87	17.51	17.
5.02	6.48	11.52	15.54	16.89	17.14	17.40	17.65	17.92	18.18	18.45	18.73	18.78	18.38	18.40	18.13	17.87	17.61	17.35	17.
4.95	6.29	10.01	10.15	10.31	10.45	10.62	10.78	10.94	11.10	11.27	11.29	11.21	10.95	10.69	10.73	10.57	10.42	10.0	
2.78	4.21	5.48	6.58	6.78	6.88	6.98	7.08	7.19	7.29	7.33	7.29	7.19	7.08	6.98	6.88	6.73	6.		
2.13	4.29	5.48	6.58	6.78	6.88	6.98	7.08	7.19	7.29	7.33	7.29	7.19	7.08	6.98	6.88	6.73	6.		

THE INPUT PATTERN IS

2.397895 , 2.397895 , 2.397895 , 2.397895 , 0.6931472 , 0.6931472 , 2.397895

THE SYSTEM RESPONSE IS

4.29	2.13	4.29	8.48	5.58	5.58	6.78	6.88	6.98	7.08	7.19	7.29	7.33	7.29	7.19	7.08	8.98	6.88	6.78
5.59	2.13	7.13	10.01	10.16	10.31	10.46	10.52	10.78	10.94	11.10	11.27	11.29	11.21	11.05	10.89	10.73	10.57	10.42
8.45	2.13	10.01	15.10	15.33	15.56	15.79	16.02	16.26	16.51	16.75	17.00	17.03	16.95	16.70	16.45	16.21	15.98	15.74
8.59	2.13	10.16	15.31	15.56	15.79	16.02	16.26	16.51	16.75	17.00	17.25	17.28	17.20	16.95	16.70	16.45	16.21	15.98
8.70	2.13	10.31	15.56	15.79	16.02	16.26	16.51	16.75	17.00	17.25	17.51	17.54	17.45	17.20	16.95	16.70	16.45	16.21
8.83	2.13	10.46	15.79	16.02	16.26	16.51	16.75	17.00	17.25	17.51	17.77	17.80	17.71	17.45	17.20	16.95	16.70	16.45
8.97	2.13	10.62	16.02	16.26	16.51	16.75	17.00	17.25	17.51	17.77	18.03	18.06	17.98	17.71	17.45	17.20	16.95	16.70
9.10	2.13	10.78	16.26	16.51	16.75	17.00	17.25	17.51	17.77	18.03	18.30	18.33	18.24	17.98	17.71	17.45	17.20	16.95
9.24	2.13	10.94	16.51	16.75	17.00	17.25	17.51	17.77	18.03	18.30	18.57	18.60	18.51	18.24	17.98	17.71	17.45	17.20
9.37	2.13	11.10	16.75	17.00	17.25	17.51	17.77	18.03	18.30	18.57	18.84	18.88	18.78	18.51	18.24	17.98	17.71	17.45
9.51	2.13	11.27	17.00	17.25	17.51	17.77	18.03	18.30	18.57	18.84	19.12	19.15	19.06	18.78	18.51	18.24	17.98	17.71
9.51	2.13	11.29	17.03	17.29	17.54	17.80	18.06	18.33	18.60	18.88	19.15	19.19	19.10	18.82	18.54	18.27	18.01	17.74
9.46	2.13	11.21	16.95	17.20	17.45	17.71	17.98	18.24	18.51	18.78	19.06	19.10	19.00	18.73	18.45	18.19	17.92	17.66
9.32	2.13	11.05	16.70	16.95	17.20	17.45	17.71	17.98	18.24	18.51	18.54	18.45	18.19	17.92	17.66	17.40	17.15	16.90
9.19	2.13	10.89	16.45	16.70	16.95	17.20	17.45	17.71	17.98	18.24	18.51	18.54	18.45	18.19	17.92	17.66	17.40	17.15
9.05	2.13	10.73	16.21	16.45	16.70	16.95	17.20	17.45	17.71	17.98	18.24	18.27	18.19	17.92	17.66	17.40	17.15	16.90
8.92	2.13	10.57	15.98	16.21	16.45	16.70	16.95	17.20	17.45	17.71	17.98	18.01	17.92	17.66	17.40	17.15	16.90	16.65
8.70	2.13	10.42	15.74	15.98	16.21	16.45	16.70	16.95	17.20	17.45	17.71	17.74	17.66	17.40	17.15	16.90	16.65	16.40
8.66	2.13	10.26	15.51	15.74	15.98	16.21	16.45	16.70	16.95	17.20	17.45	17.49	17.40	17.15	16.90	16.65	16.40	16.16
8.53	2.13	10.11	15.28	15.51	15.74	15.98	16.21	16.45	16.70	16.95	17.20	17.23	17.15	16.90	16.65	16.40	16.16	15.93
8.41	2.13	9.96	15.06	15.29	15.51	15.74	15.98	16.21	16.45	16.70	16.95	16.98	16.90	16.65	16.40	16.16	15.93	15.69
4.06	2.13	5.59	8.45	8.58	8.70	8.83	8.97	9.10	9.24	9.37	9.51	9.51	9.46	9.32	9.19	9.05	8.92	8.79
2.78	2.13	2.78	4.95	5.02	5.09	5.17	5.25	5.32	5.40	5.48	5.57	5.58	5.57	5.48	5.40	5.32	5.25	5.17

THE SISTER'S RESPONSE IS:

4.13	4.29	4.97	5.04	5.12	5.19	5.27	5.35	5.43	5.51	5.59	5.60	5.61	5.62	5.63	5.60	5.22	5.15	5.0	
5.62	5.62	5.62	5.62	5.62	5.62	5.62	5.62	5.62	5.62	5.62	5.62	5.62	5.62	5.62	5.62	5.62	5.62	5.62	
2.74	7.11	8.45	8.58	8.70	8.83	8.97	9.10	9.24	9.37	9.51	9.56	9.58	9.52	9.18	9.05	8.92	8.79	8.6	
3.55	1.21	4.95	9.94	13.52	13.72	13.93	14.14	14.35	14.55	14.74	15.0	15.22	15.28	15.47	15.67	15.73	14.51	14.30	14.09
8.42	3.39	5.02	10.14	13.72	13.93	14.14	14.35	14.55	14.74	15.0	15.22	15.28	15.47	15.67	15.73	14.51	14.30	14.09	13.6
6.53	3.44	5.09	10.29	13.93	14.14	14.35	14.55	14.74	15.0	15.22	15.28	15.47	15.67	15.73	15.24	15.34	15.17	14.94	14.73
8.65	3.49	5.17	10.44	14.14	14.35	14.55	14.74	15.0	15.22	15.44	15.67	15.91	15.97	15.35	15.62	15.39	15.17	14.94	14.73
8.74	3.54	5.25	10.60	14.35	14.55	14.74	15.0	15.22	15.44	15.67	15.91	15.94	15.20	15.39	15.35	15.62	15.39	15.17	14.94
6.92	3.59	5.32	10.75	14.55	14.74	15.0	15.22	15.44	15.67	15.91	15.94	15.20	15.39	15.35	15.62	15.39	15.17	14.94	14.73
9.05	3.65	5.40	10.91	14.78	15.00	15.22	15.44	15.67	15.91	15.94	15.20	15.39	15.35	15.62	15.39	15.17	14.94	14.73	14.6
9.18	3.70	5.48	11.08	15.00	15.22	15.44	15.67	15.91	15.94	15.20	15.39	15.35	15.62	15.39	15.17	14.94	14.73	14.6	14.5
9.32	3.76	5.57	11.24	15.22	15.44	15.67	15.91	15.94	15.38	15.62	15.87	15.93	15.81	15.37	15.32	15.09	15.85	15.62	15.39
9.45	3.81	5.58	11.25	15.28	15.50	15.73	15.95	15.20	15.44	15.58	15.93	15.18	15.25	15.12	15.87	15.63	15.39	15.15	15.0
9.51	3.85	5.57	11.19	15.22	15.44	15.67	15.91	15.94	15.38	15.62	15.87	17.12	17.18	17.05	15.81	15.57	15.32	15.09	15.85
9.46	3.86	5.48	11.03	15.00	15.22	15.44	15.67	15.91	15.94	15.38	15.62	15.87	15.93	15.31	15.37	15.33	15.09	15.85	15.62
9.32	3.81	5.40	10.85	14.78	15.00	15.22	15.44	15.67	15.91	15.34	15.38	15.62	15.68	15.37	15.33	15.09	15.85	15.62	15.39
9.19	3.75	5.32	10.70	14.56	14.78	15.00	15.22	15.44	15.67	15.91	15.34	15.38	15.64	15.33	15.09	15.85	15.62	15.39	15.17
9.05	3.70	5.25	10.55	14.35	14.56	14.78	15.00	15.22	15.44	15.67	15.91	15.34	15.38	15.64	15.33	15.09	15.85	15.62	15.39
8.92	3.64	5.17	10.39	14.14	14.35	14.56	14.78	15.00	15.22	15.44	15.67	15.91	15.36	15.35	15.62	15.39	15.17	14.95	14.
8.79	3.59	5.09	10.24	13.93	14.14	14.35	14.56	14.78	15.00	15.22	15.44	15.67	15.73	15.32	15.39	15.17	14.95	14.73	14.51
8.65	3.54	5.02	10.09	13.72	13.93	14.14	14.35	14.56	14.78	15.00	15.22	15.44	15.50	15.39	15.17	14.95	14.73	14.51	14.
8.53	3.48	4.95	9.94	13.52	13.72	13.93	14.14	14.35	14.56	14.78	15.00	15.22	15.28	15.17	14.95	14.73	14.51	14.30	13.
8.41	3.43	2.74	5.57	5.23	5.55	5.58	5.81	5.94	5.08	5.21	5.35	5.49	5.53	5.39	5.35	5.21	5.08	5.94	5.81
5.57	2.74	5.13	5.95	5.02	5.09	5.17	5.25	5.32	5.40	5.43	5.57	5.58	5.37	5.49	5.40	5.32	5.25	5.17	5.
4.73	2.74	4.95	5.02	5.09	5.17	5.25	5.32	5.40	5.43	5.57	5.58	5.37	5.49	5.40	5.32	5.25	5.17	5.	5.

THE SYSTEM RESPONSE IS

2.73	2.13	2.73	4.95	5.02	5.09	5.17	5.25	5.32	5.40	5.43	5.57	5.58	5.57	5.63	5.40	5.32	5.25	5.17	5.0
1.95	2.73	3.05	5.59	7.09	7.10	7.21	7.31	7.42	7.53	7.64	7.75	7.78	7.76	7.84	7.53	7.42	7.31	7.21	7.0
5.89	4.95	6.89	11.94	12.12	12.30	12.48	12.67	12.85	13.05	13.24	13.44	13.47	13.49	13.63	13.05	12.86	12.67	12.43	12.0
7.09	5.02	7.00	12.12	12.30	12.48	12.67	12.85	13.05	13.24	13.44	13.64	13.67	13.61	13.44	13.24	13.05	12.86	12.67	12.4
7.10	5.02	7.10	12.30	12.48	12.67	12.86	13.05	13.24	13.44	13.64	13.84	13.87	13.84	13.64	13.44	13.24	13.05	12.86	12.67
5.99	5.17	7.21	12.48	12.67	12.86	13.05	13.24	13.44	13.64	13.84	14.05	14.08	14.05	13.84	13.64	13.44	13.24	13.05	12.86
7.21	5.17	7.31	12.57	12.85	13.05	13.24	13.44	13.64	13.84	14.05	14.25	14.29	14.25	14.05	13.84	13.64	13.44	13.24	13.0
7.31	5.25	7.42	12.85	13.05	13.24	13.44	13.64	13.84	14.05	14.25	14.45	14.50	14.45	14.25	14.05	13.84	13.64	13.44	13.0
7.42	5.32	7.53	13.05	13.24	13.44	13.64	13.84	14.05	14.25	14.45	14.68	14.71	14.59	14.45	14.25	14.05	13.84	13.64	13.0
7.53	5.40	7.64	13.24	13.44	13.64	13.84	14.05	14.25	14.45	14.68	14.90	14.93	14.79	14.63	14.46	14.25	14.05	13.84	13.
7.64	5.48	7.75	13.44	13.64	13.84	14.05	14.25	14.45	14.68	14.90	15.12	15.15	15.12	14.97	14.68	14.46	14.25	14.05	13.84
7.75	5.57	7.78	13.47	13.67	13.87	14.08	14.27	14.50	14.71	14.93	15.15	15.18	15.15	14.93	14.71	14.50	14.29	14.08	13.
7.85	5.58	7.76	13.44	13.64	13.84	14.05	14.25	14.45	14.68	14.90	15.12	15.15	15.12	14.90	14.68	14.46	14.25	14.05	13.
7.76	5.57	7.64	13.24	13.44	13.64	13.84	14.05	14.25	14.45	14.68	14.90	14.93	14.79	14.63	14.46	14.25	14.05	13.84	13.
7.64	5.48	7.53	13.05	13.24	13.44	13.64	13.84	14.05	14.25	14.45	14.68	14.71	14.59	14.36	14.25	14.05	13.84	13.64	13.
7.53	5.40	7.42	12.86	13.05	13.24	13.44	13.64	13.84	14.05	14.25	14.45	14.50	14.45	14.25	14.05	13.84	13.64	13.44	13.
7.42	5.32	7.31	12.57	12.85	13.05	13.24	13.44	13.64	13.84	14.05	14.25	14.29	14.25	14.05	13.84	13.64	13.44	13.24	13.
7.31	5.25	7.21	12.48	12.67	12.86	13.05	13.24	13.44	13.64	13.84	14.05	14.08	14.05	13.84	13.64	13.44	13.24	13.05	12.
7.21	5.17	7.10	12.30	12.48	12.67	12.85	13.05	13.24	13.44	13.64	13.84	13.87	13.84	13.64	13.44	13.24	13.05	12.86	12.
7.10	5.09	7.00	12.12	12.30	12.48	12.67	12.85	13.05	13.24	13.44	13.64	13.67	13.54	13.44	13.24	13.05	12.86	12.67	12.
7.09	5.02	6.89	11.94	12.12	12.30	12.48	12.67	12.85	13.05	13.24	13.44	13.47	13.44	13.24	13.05	12.86	12.67	12.43	12.
5.89	4.95	4.95	5.89	7.09	7.10	7.21	7.31	7.42	7.53	7.64	7.75	7.78	7.76	7.54	7.33	7.12	6.91	6.70	6.49
5.82	4.73	4.05	5.89	7.09	7.10	7.21	7.31	7.42	7.53	7.64	7.75	7.78	7.76	7.54	7.33	7.12	6.91	6.70	6.49
2.73	2.13	2.72	4.95	5.02	5.09	5.17	5.25	5.32	5.40	5.48	5.57	5.58	5.57	5.48	5.40	5.32	5.25	5.17	5.

THE INPUT PATTERN 15

~~0.6931472~~ , ~~0.6931472~~ , ~~2.397895~~ , ~~2.397895~~ , ~~0.6931472~~ , ~~0.6931472~~ , ~~2.397895~~

THE SYSTEM SUSPENSE IS

THE SYSTEM RESPONSE IS																		
1.23	0.62	1.02	1.37	1.90	1.93	1.95	1.94	2.02	2.05	2.03	2.01	2.02	2.03	2.04	2.05	2.02	1.99	1.95
4.01	0.62	1.24	4.01	5.31	5.39	5.47	5.55	5.63	5.72	5.81	5.89	5.93	5.97	5.99	5.90	5.72	5.63	5.55
6.85	1.24	1.87	5.31	6.78	8.91	9.04	9.17	9.31	9.45	9.59	9.73	9.83	9.95	9.73	9.78	9.64	9.50	9.36
3.39	1.90	5.39	6.91	9.04	9.17	9.31	9.45	9.59	9.73	9.83	9.95	9.73	9.78	9.64	9.50	9.36	9.22	
6.95	3.44	1.93	5.47	9.04	9.17	9.31	9.45	9.59	9.73	9.83	9.95	9.73	9.78	9.64	9.50	9.36	9.22	
7.25	3.49	1.96	5.65	9.17	9.31	9.45	9.59	9.73	9.88	10.02	10.17	10.32	10.46	10.38	10.23	10.08	9.93	
7.16	3.54	1.99	5.63	9.31	9.45	9.59	9.73	9.88	10.02	10.17	10.32	10.46	10.38	10.23	10.08	9.93	9.78	
7.25	3.59	2.02	5.72	9.45	9.59	9.73	9.88	10.02	10.17	10.32	10.48	10.55	10.38	10.38	10.23	10.08	9.93	
7.31	3.65	2.05	5.80	9.59	9.73	9.88	10.02	10.17	10.32	10.48	10.63	10.72	10.59	10.53	10.38	10.23	10.08	
7.43	3.70	2.08	5.89	9.73	9.88	10.02	10.17	10.32	10.48	10.63	10.72	10.81	10.69	10.53	10.38	10.23	10.08	
7.59	3.76	2.11	5.98	9.88	10.02	10.17	10.32	10.48	10.63	10.72	10.85	11.01	11.01	10.89	10.53	10.38	10.23	
7.71	3.81	2.12	6.02	9.96	10.11	10.26	10.41	10.56	10.72	10.87	11.03	11.20	11.01	11.27	11.01	10.84	10.69	10.53
7.78	3.85	2.11	5.98	9.93	10.08	10.23	10.38	10.53	10.69	10.81	11.01	11.17	11.25	11.23	11.05	10.90	10.74	10.59
7.75	3.86	2.08	5.89	9.78	9.93	10.08	10.23	10.38	10.53	10.69	10.84	11.01	11.17	11.06	10.90	10.74	10.59	10.43
7.64	3.81	2.05	5.80	9.54	9.78	9.93	10.08	10.23	10.38	10.53	10.69	10.84	10.91	10.70	10.74	10.59	10.43	10.28
7.53	3.75	2.02	5.72	9.50	9.64	9.78	9.93	10.08	10.23	10.38	10.53	10.69	10.74	10.71	10.59	10.43	10.28	10.13
7.42	3.70	1.99	5.63	9.36	9.50	9.64	9.78	9.93	10.08	10.23	10.38	10.53	10.69	10.74	10.71	10.59	10.43	10.28
7.31	3.64	1.96	5.55	9.22	9.36	9.50	9.64	9.78	9.93	10.08	10.23	10.38	10.53	10.67	10.57	10.43	10.28	10.13
7.21	3.59	1.93	5.47	9.09	9.22	9.36	9.50	9.64	9.78	9.93	10.08	10.23	10.38	10.51	10.43	10.28	10.13	9.98
7.10	3.54	1.90	5.39	8.95	9.09	9.22	9.36	9.50	9.64	9.78	9.93	10.08	10.18	10.13	9.98	9.84	9.69	9.55
7.00	3.48	1.87	5.31	8.82	8.95	9.09	9.22	9.36	9.50	9.64	9.78	9.93	10.01	9.98	9.84	9.69	9.55	9.41
6.89	3.43	1.84	4.01	5.35	5.95	7.05	7.15	7.25	7.37	7.48	7.69	7.71	7.71	7.76	7.64	7.63	7.42	7.31
5.57	2.73	0.02	1.02	5.39	5.93	5.99	5.94	5.94	5.94	5.95	5.97	5.98	5.98	5.95	5.91	5.75	5.70	5.64
2.73	2.13	0.02	1.02	5.39	5.93	5.99	5.94	5.94	5.94	5.95	5.97	5.98	5.98	5.95	5.91	5.75	5.70	5.59

THE INPUT PATTERN IS																			
2.397895	, 0.6931472	, 0.6931472	, 0.6931472	, 0.6931472	, 0.6931472	, 0.6931472	, 0.6931472	, 0.6931472	, 0.6931472	, 0.6931472	, 0.6931472	, 0.6931472	, 0.6931472	, 0.6931472	, 0.6931472	, 0.6931472			
THE SYSTEM RESPONSE IS																			
1.24	2.13	2.78	3.43	3.48	3.54	3.59	3.64	3.70	3.75	3.81	3.86	3.85	3.81	3.76	3.70	3.65	3.59	3.54	
	0.62	2.78	4.06	5.36	5.44	5.52	5.60	5.68	5.77	5.85	5.94	6.03	6.02	5.98	5.99	5.90	5.72	5.63	5.55
2.50	1.24	3.43	5.36	7.31	7.42	7.53	7.64	7.76	7.87	7.99	8.11	8.23	8.23	8.17	8.05	7.94	7.82	7.71	7.59
3.77	1.87	3.48	5.44	7.42	7.53	7.64	7.76	7.87	7.99	8.11	8.23	8.35	8.35	8.30	8.17	8.05	7.94	7.82	7.71
3.83	1.90	3.54	5.52	7.53	7.64	7.76	7.87	7.99	8.11	8.23	8.35	8.47	8.48	8.42	8.30	8.17	8.05	7.94	7.82
3.89	1.93	3.59	5.60	7.61	7.76	7.87	7.99	8.11	8.23	8.35	8.47	8.60	8.60	8.54	8.42	8.30	8.17	8.05	7.94
3.95	1.96	3.64	5.68	7.76	7.87	7.99	8.11	8.23	8.35	8.47	8.60	8.73	8.73	8.67	8.54	8.42	8.30	8.17	8.05
4.00	1.99	3.70	5.77	7.87	7.99	8.11	8.23	8.35	8.47	8.60	8.73	8.85	8.86	8.80	8.67	8.54	8.42	8.30	8.17
4.06	2.02	3.75	5.85	7.99	8.11	8.23	8.35	8.47	8.60	8.73	8.85	8.99	8.99	8.93	8.80	8.67	8.54	8.42	8.30
4.13	2.05	3.81	5.94	8.11	8.23	8.35	8.47	8.60	8.73	8.85	8.99	9.12	9.12	9.06	8.93	8.80	8.67	8.54	8.42
4.19	2.08	3.86	6.03	8.23	8.35	8.47	8.60	8.73	8.85	8.99	9.12	9.25	9.26	9.19	9.06	8.93	8.80	8.67	8.54
4.25	2.11	3.85	6.02	8.23	8.35	8.48	8.60	8.73	8.86	8.99	9.12	9.25	9.26	9.20	9.07	8.93	8.80	8.68	8.55
4.27	2.12	3.81	5.99	8.17	8.30	8.42	8.54	8.67	8.80	8.93	9.06	9.19	9.20	9.14	9.00	8.87	8.74	8.62	8.49
4.25	2.11	3.76	5.89	8.05	8.17	8.30	8.42	8.54	8.67	8.80	8.93	9.08	9.07	9.00	8.87	8.74	8.62	8.49	8.37
4.19	2.08	3.70	5.80	7.94	8.05	8.17	8.30	8.42	8.54	8.67	8.80	8.93	8.93	8.87	8.74	8.62	8.49	8.37	8.24
4.13	2.05	3.65	5.72	7.82	7.94	8.05	8.17	8.30	8.42	8.54	8.67	8.80	8.80	8.74	8.62	8.49	8.37	8.24	8.12
4.06	2.02	3.58	5.63	7.71	7.82	7.94	8.05	8.17	8.30	8.42	8.54	8.67	8.68	8.62	8.49	8.37	8.24	8.12	8.00
4.00	1.90	3.54	5.55	7.59	7.71	7.82	7.94	8.05	8.17	8.30	8.42	8.54	8.55	8.49	8.37	8.24	8.12	8.00	7.89
3.95	1.96	3.40	5.47	7.48	7.59	7.71	7.82	7.94	8.05	8.17	8.30	8.42	8.42	8.37	8.24	8.12	8.00	7.89	7.77
3.89	1.93	3.44	5.39	7.37	7.48	7.59	7.71	7.82	7.94	8.05	8.17	8.30	8.30	8.24	8.12	8.00	7.89	7.77	7.66
3.83	1.90	3.39	5.31	7.26	7.37	7.48	7.59	7.71	7.82	7.94	8.05	8.17	8.18	8.12	8.00	7.89	7.77	7.65	7.55
3.77	1.87	3.24	2.50	3.77	3.83	3.89	3.95	4.00	4.06	4.13	4.19	4.25	4.27	4.25	4.19	4.13	4.06	4.00	3.95
2.50	1.24	0.62	1.24	1.67	1.90	1.93	1.96	1.99	2.02	2.05	2.08	2.11	2.12	2.11	2.08	2.05	2.02	1.99	1.96